STUDY OF INDUSTRY 4.0 IMPLEMENTATION IN MANUFACTURING COMPANIES

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All information in this thesis have been obtained and presented in accordance with existing academic rules and ethical conduct. I declare that, as required by these rules and conduct, I have fully cited and referred all materials and results that are not original to this work.

I also declare that I have checked this thesis as per the "Policy on Anti Plagiarism, Jadavpur University, 2019", and the level of similarity as checked by iThenticate software is **2%.**

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LIST OF ABBREVIATIONS

AHP: Analytical Hierarchy Process
AI: Artificial Intelligence
AM: Additive Manufacturing
ANP: The AHP and Analytic Network Process
AR: Augmented Reality
BDA: Big Data Analytics
BMW: Best Worst Method
CC: Cloud Computing
CDE: Circular Dynamic Environment
CEP: Circular Economy Practices
CI: Capital Investments
COPRAS: Complex Proportional Assessment Method
CPS: Cyber-Physical System
CRITIC: Criteria Importance Through Inter-criteria Correlation
DC: Dynamic Capabilities
DCV: Dynamic Capability View Theory
DEA: Data envelopment analysis
DEMATEL: Decision-Making Trial and Evaluation Laboratory method
DL: Digital Leadership
EE: Employee Empowerment
FAHP: Fuzzy Analytical Hierarchy Process
FTOPSIS: Fuzzy Technique for Order of Preference by Similarity to Ideal Solution
GDP: Gross Domestic Product
I4.0: Industry 4.0
I4A: I4.0 adoption
I4S: Industry 4.0 Standards
I4T: Industry 4.0 Technologies
IC: Innovation Capabilities
IGP: Innovation in Green Processes
IIoT: Industrial Internet of Things (),
IoT: Internet of Things
IR: Investment Recovery
ISM: Interpretive Structural Modeling
IT: Information Technology
KPIs: Key Performance Indicators
KSFs: Key Success Factors
MABAC: Multi-Attributive Border Approximation Area Comparison Method
MCDM: Multi-Criteria Decision-Making Method
MICMAC: Matriced’ Impacts Croise´s Multiplication Applique´e a´ un Classement
ML: Machine Learning
MOORA: Multi-Objective Optimization on basis of Ratio Analysis
OS: Organizational Strategies
PROMETHEE: Preference Ranking Organization METHod for Enrichment of Evaluations
RM: Risks Mitigation
SCA: Supply Chain Agility
SEC: Stakeholders as Employees and Customers
SLR: Systematic Literature Review

SMEs: Small to Medium Enterprise
SOP: Sustainable Organizational Performance
SPO: Smart Products and Operations
VIKOR: VIseKriterijumska Optimizacija I Kompromisno Resenje
VR: Virtual Reality

ABSTRACT

Over the past few years, especially in the manufacturing sector, the world has experienced an incredible infusion of technology. Industry 4.0 (I4.0) is evolving mainly because of its potential impacts on society, the economy, and the manufacturing industry. Due to this, several countries have started to develop strategies and policies to implement cutting-edge digitization practices in their companies. The majority of business operations have undergone substantial digitalization and automation in response, which has increased each one's speed, dependability, adaptability, and agility while also reducing costs. Additionally, the COVID-19 pandemic, which created chaos in supply chains and organization management globally, has systematically boosted the progression of I4.0 technologies during and after the COVID-19 era.

Hence, the manufacturing sector has anticipated a considerable influence of I4.0 on its business models, supply networks, and operations in the current environment. However, most of them still don't fully understand its intricate features. Poorly thought-out and haphazardly implemented ideas are never intended to alter the situation. Therefore, only a few who dared to commit fully to I4.0 may benefit from being first in the competition. There are several concerns about its organizational structure, technological capabilities, and techniques for attaining the I4.0 vision. Due to a lack of knowledge about I4.0's current condition and insufficient direction and support in its digital transformation efforts, the majority of businesses worldwide struggle to embrace it successfully. Therefore, to address this problem, stakeholders must be informed of the driving forces behind its adoption and how it would help them achieve sustainable organizational performance (SOP). However, the support provided by the Indian government in the areas of legislation, infrastructure development, and fundamental education reform is having a good effect on the companies and encouraging them to adopt I4.0.

This study intends to comprehend how Indian manufacturing organizations perceive the I4.0 vision's implementation in the manufacturing industry and the preparations to achieve SOP to gain a competitive edge. Additionally, two exploratory case studies are integrated with a systematic survey as part of the research methodology. Exploratory case studies are performed to assess and identify the most important constructs that adopt the I4.0 implementation plan and thoroughly comprehend the fundamental issue under investigation. Thus, to address this study's research questions and objectives, a

survey of 225 manufacturing organizations is undertaken with 280 respondents from different regions of India covering a wide range of manufacturing sectors.

The first exploratory case study suggests that the most important key success factors (KSFs) in adopting the I4.0 paradigm are the internet network infrastructure and current technology status to comply with I4.0. According to study results, a reliable internet network, low latency, and seamless connectivity are all essential for the adoption of I4.0 to be effective. I4.0 practitioners and policymakers could create a roadmap and a strategic plan for its implementation by devising the policies for internet network infrastructure and organizing the deployment strategies for current technological infrastructure to comply with I4.0 requirements. Thus, this exploratory case study advises industrial firms to develop efficient policies and plans to implement I4.0, further enhancing the performance of the business.

The second exploratory case study investigation revealed that information security and cost are the most important prominence and receiver key performance indicators (KPIs). Furthermore, it has been found that both technological and social risks heavily impact I4A's decision-making process. This study advises managers, stakeholders, and policymakers to develop a thorough and robust foundation of long-term policies that will ensure the success and feasibility of I4.0 in the long term by reducing technological and social risks.

Moreover, the survey findings recommend that the organizations representing the manufacturing industry of India are at a progressing stage of I4.0 implementation. Companies have realized the importance of dynamic capabilities (DC) and circular economy practices (CEP) to achieve SOP through I4.0 adoption (I4A). The survey outcomes also reveal that the automobile sector contributes most significantly to embracing I4.0. The data show that the automobile sector has convinced that I4.0 substantially enhances SOP.

Further, the Structural Equation Modeling (SEM) study results show that the identified drivers of I4A, DC, and CEP are positively associated with I4A, DC, and CEP. Additionally, it has been demonstrated that there is a positive association between I4A and SOP, I4A and DC, DC and CEP, and CEP and SOP. Beyond that, the study also arrived at an intriguing conclusion, such as the idea that DC and CEP integration is a key mediating construct that positively mediates the association between I4A and SOP. One noteworthy finding of the study is that the indirect association of I4A and SOP is more prevalent than the direct relationship between I4A and SOP due to the mediating roles of DC and CEP. Therefore, the study recommends that company managers and practitioners focus on the possibility of integrating DC and CEP even while developing successful, concrete strategies and policies. The DC and CEP interference will increase resource efficiency and productivity by allowing the I4A to operate at its full potential. This analysis thus revealed that the establishment of DC will significantly strengthen CEP and ease the I4A for progressing towards SOP. Finally, an operational framework for I4.0 implementation in manufacturing organizations for SOP evaluation functioning in India is developed based on quantitative and qualitative literature reviews and outcomes of empirical research. The suggested framework offers advice on how to prepare for I4A and aids in offering a road map for I4A, DC, CEP, and SOP. In light of the suggested framework, this may also assist organizations in leveraging SOP in other value network companies.

This thesis enriches the body of extant research in the field of I4.0 by recommending an operational framework for achieving the SOP by integrating DC and CEP through the use of I4.0 practices. Configuring the DC and CEP resources and capabilities to meet the SOP target may encourage companies to evaluate their own readiness for I4.0. This will assist organizations in prioritizing the steps for improvements in their organization. By assessing I4.0 KPIs, KSFs, and risks, the current study provides a comprehensive portrait of how Indian manufacturing companies are prepared for I4.0. Additionally, to successfully implement I4.0, a plan of action is developed using the research findings to promote the important KPIs and KSFs, mitigate the impact of significant risks, and eliminate or reduce those risks. By carefully handling I4A, DC, CEP, and SOP, the recommendations made in the study will help managers and policymakers to confront the dynamic nature of business. Moreover, it will balance the company’s contingencies to gain a competitive advantage. This study is, therefore, the first of its kind and offers a distinctive contribution to the literature and practitioners.

1 Introduction

1.1 Overview

Industry 4.0 (I4.0), widely recognized as the "Fourth generation industrial revolution," has attracted interest from academics, researchers, the government, and social and industrial systems worldwide in recent years. Since I4.0 was initially unveiled at the Hannover exhibition in Germany in 2011, it has been the subject of discussion and deliberation in every international forum, either directly or indirectly. Various technologies are combined to provide flexible, rapid, and high-quality production, ultimately encouraging efficient and sustainable business management (Bai et al., 2020). Its seamless interconnection and data exchange among all manufacturing equipment and machines is one of the numerous advantages of the I4.0 new technologies that set them apart from the old conventional technique (Bauer et al., 2015). The Internet of Things (IoT), Big Data Analytics (BDA), Industrial Internet of Things (IIoT), Machine Learning (ML), Artificial Intelligence (AI), Cloud Computing (CC), Cyber-Physical Systems (CPS), Robots and Cobots, Additive Manufacturing (AM), Augmented Reality/Virtual Reality (AR/VR), and Digital Twin, all contribute to the global manufacturing industry's overall digital transformation (Arbabian and Wagner, 2020; Türkeş et al., 2019). **Figure 1.1** outlines the major I4.0 technologies essential to their roles in real-world situations. I4.0 is a technological shift toward highly advanced manufacturing and environmentally friendly production methods (Roblek et al., 2016). As a new organizational epitome that smartly manages the entire industrial value chain. I4.0 has great potential for product customization, flexibility, quality improvement, cost-effectiveness, and unheard-of speed in business processes, according to industrial companies that have adopted it partially or entirely (Ghobakhloo, 2020; Wang, 2018). According to Nalubega and Uwizeyimana (2019) and Erasmus (2021), the industrial sector will benefit from the I4A only after the local administration and governance are ready to integrate the I4.0 vision into the national policy. The overarching goal of this research is to assist industry and advance our understanding of Industry 4.0. While because of the lack of understanding and clarity regarding returns on investment and anticipated results, the I4A in the manufacturing industries has not been as smooth and straightforward (Chauhan et al., 2021). The

COVID-19 epidemic also made things worse by exposing the unprepared industry to unexpected challenges with cleaning, social isolation, a lack of medical facilities, and inadequate funding (Adámek and Meixnerová, 2020). Surprisingly, most sectors that did not start the digitalization process within their organizations came to a standstill. While most firms forcefully agreed to the situation, some considered this an opportunity to advance or start their digital transformation (Mofijur et al., 2021).

Making it simpler for businesses to conduct their operations remotely is one of the objectives of digitization, which will provide them a competitive edge and is a crucial part of the new normal that has evolved as a result of the epidemic. The manufacturing industries face a wide range of opportunities and obstacles that have never been faced before with adopting the promising technologies outlined above (Ben-Daya et al., 2017). Opportunities abound, but barriers including a lack of resources (both financial and ecological), a lack of technological standards, a shortage of IT infrastructure, and inadequate data security precautions prevent I4.0 from thriving (Luthra and Mangla, 2018; Mckinsey, 2021). Additionally, these concerns' uncertain nature and scope prevent decision-makers from taking swift action, thereby worsening the risks involved in I4.0 execution (Birkel et al., 2019).

The outcomes from comprehensive SLR exhibit that earlier studies ignored the connections between I4A, DC, CEP, and SOP, which every company aspires for and focuses on building their capacities and planning optimum resource utilization. And only took into account operational performance, I4.0 barriers, and I4A (Chauhan et al., 2021), I4.0 technologies (I4T), and lean manufacturing impacting SOP (S. S. Kamble et al., 2020), I4A and green supply chain management (Ghadge et al., 2020), innovations and circular economy (CE) (Suchek et al., 2021). Thus, countries must create national policies worldwide, and companies must create company-specific, customized, and adaptive solutions, strategies, and standards for I4A to leverage the SOP. In light of the discussion above, this study first thoroughly evaluates the relevant literature using quantitative (bibliometric analysis) and qualitative (SLR) methodologies. Additionally, the exploratory case studies to comprehend the importance of KSF and their KPI-based assessment along with KPI-based I4.0 risks assessment helps to extract the final constructs for the research and provides an overview of the current status of I4.0 in the Indian environment. In order to better understand how I4A, DC, CEP, and SOP interplay within Indian manufacturing businesses, a survey is also undertaken. Additionally, an effort is made to offer a systematic implementation plan for the I4.0 vision for Indian manufacturing businesses, with discussions and ramifications on the study findings coming after the conclusion.

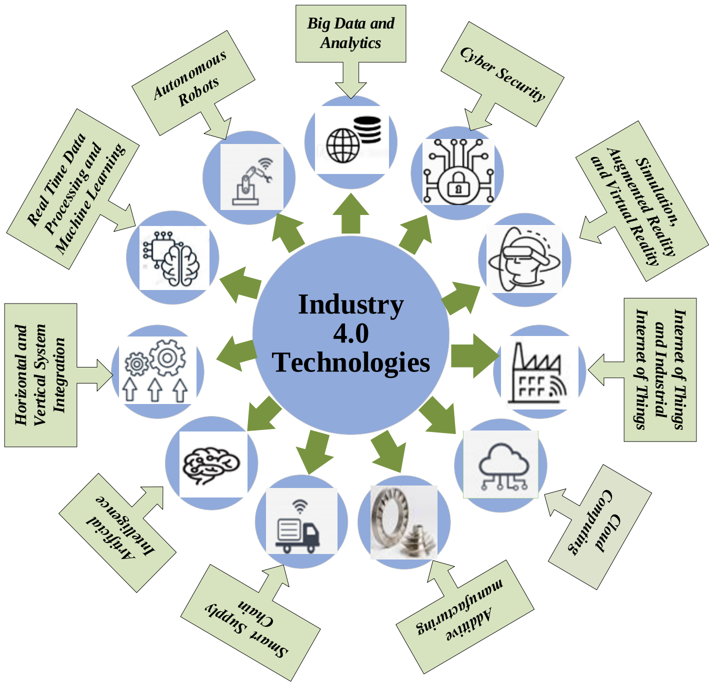

Figure 1.1: Amalgamation of Prominent Industry 4.0 Technologies

1.2 Research Motivation

The manufacturing industry in India is one of the economy's largest sectors and a contributor to the Gross Domestic Product (GDP) (Kamble et al., 2018b). Barring few in this sector, many still do not have clarity about digitalization in business functionalities, mainly because of the limited knowledge, awareness, negatively perceived implications, and absence of proven frameworks. In addition to the first movers, a few Indian companies, after surviving the COVID-19 pandemic, realized the importance of digitalization and the application of emerging technologies in enhancing product quality and differentiation from others in the market (Chao et al., 2021). All said and done; many are still at a crossroads as their challenges are complex, real, and critical, requiring exhaustive empirical research. This motivates the researcher to investigate the dominating constructs stopping companies from implementing I4.0 practices partly or fully. One of the strongest motivations for this research is to propose a model that will guide companies toward adopting fast, flexible, and more reliable operations in manufacturing organizations. It further seeks to develop this model to integrate existing resources and emerging technologies effectively. This study is conducted in India, which is in a progressive stage of immersing digitalization compared to the global scenario. The government's aspirations to fully embrace digitization are unequivocal, supported by legislation, policies, and strategies, and they are yielding results, albeit slowly. The government has formulated and implemented many schemes and policies at the grass root level to revamp the economy and role of each industry. Mainly manufacturing industries, aiming for inclusive growth in the country like "Make in India," "Digital India," "SAMARTH Udyog Bharat 4.0," etc., creating opportunities and means to mitigate the challenges of the I4.0 urgently. Today India has a vision and thoughtfully developed an integrated national strategy to respond to the emergence of I4.0 to ensure competitiveness across economic sectors (Govender and Reddy, 2019).

Amongst all those companies, which form part of this study, public sector companies, even though they have a clear mandate, are found to be slow because of red-tapism, whereas private companies are slow because of the high investments and risks (Gadekar et al., 2020; Govender and Reddy, 2019). In addition, small to micro companies do not have a digital strategy or vision to harness the opportunities compliant with I4.0 (Chauhan et al., 2021). Thus, today's business environment is very dynamic and uncertain. Therefore, the only logical course of action in this uncertain economic ecosystem is to create a credible, practical, and significant framework for allocating and considering DCs (Teece, 2014). The environment's integrity cannot be compromised simultaneously; thus, CEPs must be the top priority during and after the I4.0 deployment (Edwin Cheng et al., 2021). A company's ability to meet its stakeholders' requirements while continuously improving its organizational and financial plans and tactics to sustain long-term economic gain, developmental issues, and environmental health is the essence of an organization's SOP (Pantelica et al., 2016). Therefore, this DC and CEP-based analysis is necessary for identifying the critical relationship between I4A and SOP. Ignorance of such a relationship could significantly negatively impact an industry's overall health (Moeuf et al., 2020). Few studies have attempted to address this topic but fall short of the present needs. This is, therefore, highly relevant and necessary in the current setting.

This study simplifies the complex relationship between I4.0, DC, CEPs, and SOP for stakeholders' clear understanding of each individual and relative importance in advancing the industry objectively. Efficient utilization of existing capabilities and resources considering protecting ecological systems as a priority and integrating them to best reap the benefits of an organization's SOP, which every business desperately needs. The study will also allow companies to understand their capability and capacity as a part of their readiness to integrate I4.0 practices to promote DC and CEPs and gauge their organization's competitive advantage. The KPIs evaluation greatly influences the systematic allocation of an organization's resources and capabilities (Zheng et al., 2018). Also, the risks associated with I4.0 are widely acknowledged; only systematic, scientific, and strategic methods can help mitigate their effects. Additionally, thorough and organized KPIs evaluation is necessary for creating a suitable action plan to monitor and reduce the potential negative consequences of I4.0 risks, which would help hasten I4A (Berrah et al., 2021).

As a result, this study highlights the systematic identification, evaluation, and assessment of I4.0 KSF and KPIs-based evaluation of I4.0 risks using exploratory case studies. This study's survey-based empirical evaluation of I4.0 drivers, DCs, and CEPs and their interactions will help manufacturing industry policymakers develop practical risk management plans for alleviating I4A. KSF analysis and assessments give the researchers and practitioners an edge to devise the solutions to handle DCs of organizations to promote CEPs, and I4A will further lead to achieving SOP. Undoubtedly, the lack of knowledge, particularly in the Indian context, the plan considered for the study is also a topic of interest in India. In light of this, this research must acquire insight into the rapid adoption of I4.0 in emerging countries like India.

1.3 Significance of the Study

This research is being carried out in India mainly to assist the manufacturing industry but not limited to it. The prime objective is to assist the industry in gaining a wider perspective of the I4.0 practices and implications on present and future business practices. This study started pre-pandemic and continued during the highs and lows of the pandemic. Evidently, the pandemic has changed the business world. Those who could not sustain the sudden change, followed by extensive digitalization, went out of business (Kemi and Chijioke, 2021). The pandemic worst hits SMEs as most of them were unprepared for such a jerk. Many of them could not adopt the new technology and meet the extremely customized demand, which ultimately shut down their businesses (Beharry-Ramraj and Tshabalala, 2021). The pandemic has caused unimaginable losses as well as an acceleration in technology adoption. Undoubtedly, it will be known more for job losses, economic decline, loss of GDP, and millions of lives globally (Beharry-

Ramraj and Kwela-Mdluli, 2020). The remedy could be that industries must introspect into the existing business model and make necessary changes to make it sustainable by ensuring appropriate technological interventions and required skill sets (Tusev, 2018). This study is a sincere effort to devise the framework to handle such an uncertain business environment while developing appropriate DCs and focusing on CEPs to reach out to the SOP of an organization by investigating the interrelationship among them. Also, the emphasis on identifying and assessing KSFs, KPIs, and risks evaluation made this study unique and most appropriate in the current predicament. This study therefore has enormous opportunities to aid all stakeholders that strive towards I4.0 in their company and research domain, including researchers, practitioners, and stakeholders.

1.4 Study Rationale

The I4.0's advent has sparked discussions among governments all over the world about how to use the quickly expanding technology to innovate and improve the delivery of services (Beharry, A., & Pun, 2020). I4.0 has given youngsters a position in the workforce in industrialized nations and improved their abilities to lead businesses into a future that employs powerful technical solutions to create value and continual improvement (Clinton et al., 2021), emphasizing more on strengthening the DCs of the organizations. As a result of the I4.0's disruption of employees, jobs, and the workplace, businesses will need to reflect, reinvent themselves, and use cutting-edge technology to acquire and maintain a competitive advantage (Bittner, 2019). This will raise concerns about challenges, risks, and barriers relevant to I4.0 and necessitates the need for CEPs to deal with environmental issues (Birkel et al., 2019; Horváth and Szabó, 2019; Scarpellini et al., 2020b). The I4A-influenced new digital era, which has impacted individuals and the workplace through rapid technological advances, is being experienced by both public and private sector organizations (Armellini et al., 2020). I4.0's rapid technological advancements will upset boomers' expectations for joining an organization and impact several industries (Mayer and Oosthuizen, 2019). In order to attain SOP, the public sector must establish the working environment to be in line with global trends, employing the I4.0 to improve innovative revenue generation and community resources (Mayer, 2020).

Additionally, the emergence of I4.0 has led to a discrepancy between the skill set that organizations presently acquire and the kind of talents needed in the future (Adams et al., 2017). Therefore, firms must adopt I4.0 practices in order to achieve a diverse workplace culture and important strategic goals (Marciano, 2018). Some organizations have realized that the I4.0 vision requires a workforce responsive to the demands of the rapid technological advances that are taking place across industries (Erasmus, 2021) to promote DCs. This research has also shown that the emergence of the I4.0 has propelled most organizations to attract an industrial manufacturing ecosystem that is technologically driven and innovative (Oppermann, 2021), helping reinforce organizational DCs and CEPs to attain competitive advantage.

1.5 Iceberg Model for Industry 4.0 Adoption Leading to Sustainable Organizational Performance

One of the simplest and most popular research strategies for graphically displaying disproportionate inputs and limited returns is the iceberg model. The Iceberg Model has multifaced applications by virtue of its simplicity and ease of comprehension.

The ability to shift your perspective and look beyond the present events that everyone is focused on is made possible by using an iceberg model. It assists in determining the fundamental causes and causes of those occurrences. The system's more nuanced levels of abstraction can be seen in greater detail using this approach. This model has Events and Patterns as the tip of the iceberg and Structures and Mental models in the base. The following questions are posed to comprehend each level's specific cause.

- Events: What is taking place right now?
- Patterns: What has happened throughout the years? What patterns are there?
- Structures: What factors into these patterns? Where do the patterns connect?
- Mental images: What standards, presumptions, or values guide the system?

The researcher answered these crucial questions to finally identify key constructs and sub-constructs in the model upon which this research is based. The aim of using this model here is to identify the key causes under the category of I4A, CEP, and DC that trigger the effect in terms of SOP. The "Industry 4.0 adoption Leading to SOP Iceberg Model" is the product of a comprehensive study, discoveries, and the researchers' vast expertise in digitalization and intelligent technologies. The researcher has systematically assessed the interrelationship among the I4A, DC, and CEP in the beginning and then their impact individually and in combinations on SOP, as shown in **Figure 1.2**. It rationally indicates that what is seen is an outcome, but the influencing variables, sometimes far more than expected, are frequently hidden in terms of resources and capabilities (Georghiou, 2007). The unseen region undoubtedly has many concerns, challenges, and difficulties. Customers, stakeholders, and decision-makers may not always be aware of the problems at the bottom of the iceberg that are the primary sources of problems. If these issues are ignored, organizations risk suffering the terrible effects of the serious nature that are just the tip of the iceberg.

Even though the problem orientation and scope may look similar to the past in this volatile world, the trigger points are not necessarily the same or similar (Nath and Sarkar, 2020). This very aspect misleads the decision-makers in understanding the origin of a problem. Most stakeholders and governments are baffled by such conditions since there are no clear guidelines to approach these situations. Although these factors first seem enormous and terrible, the day is not far when organizations will seriously contemplate implementing I4.0, with the continual growth of knowledge for managing I4.0 hazards.

1.6 Objectives and Scope of Research Work

An organization's inclusive growth is an outcome of all the resources and capabilities contributing at an optimum level to achieve uniform growth across all the stakeholders, leading to attaining SOP. And the nation's development is the reflection of many such organizations working in different sectors. The manufacturing industry, by nature, has the maximum share in job creation and the churning economy. In order to fully comprehend the implications of adopting I4.0, it is essential to deal with comprehensive identification, assessment, and review of I4.0 KSF and KPIs-based evaluation of I4.0 risks through exploratory studies. Similarly, a well-defined and focused digitalization policy, which will integrate existing resources to create a virtual industry, can keep the industry growing fast (Gatune, 2018); this helps to gain SOP to attain a competitive advantage. Thus, the companies should have a balanced approach to managing DCs and effective resource utilization while adopting CEP based on the I4A practices and have an excellent chance to accelerate the progression of I4A.

The government of India has launched many schemes to support the digitalization vision across all sectors. It is evident from the digitalization policies and strategies formulated by the Indian government in the last decade to create a conducive environment for I4.0 (Katiyatiya, 2020). Despite governments taking all the initiatives

Figure 1.2: An Iceberg Model for Industry 4.0 Adoption Leading to Sustainable Organizational Performance

to promote digitalization, many organizations still do not have customized strategies to take advantage of I4.0 opportunities. It seems the companies are waiting for more clarity and do not want to take the risk. Hence, this study becomes important in the present context to help the industries. The manufacturing sector can still not clearly relate the swift technology transfer to its business objectives (Csath, 2018) unless it is investigated and supported logically. Limited capital, lack of innovation, costly technology, and lack of skills deter the adoption of I4.0 (Doval, 2021). Past studies have explored the critical relationship between the industry's ability to manufacture products and services using emerging technologies to meet highly demanding customers (Kim et al., 2021). However, there are minimal or no studies that could have focused on how organizations should integrate and manage I4A, especially when it is perceived as emphasizing DC and CEPs' integration in I4A and SOP relationship. Therefore, a strong, aware, and tech-savvy leader who understands the positive implications of I4A and has a systematic approach to win over the perceived adverse effect of I4.0 on all the functions within the organization must (Alen et al., 2017) drive the momentum.

The I4.0 revolution is said to have started at the beginning of the previous decade. Even after a decade, the industry has had little uptake (Gayle et al., 2021). It is not because of a lack of awareness but a lack of initiation, research, customization, and absence of the systematic, tried, and tested framework (Adams et al., 2017). This slow and hiding approach limits the I4.0 progression, thereby keeping companies from harnessing the best of the I4.0 revolution (Alade et al., 2021). Thus, this confirms the need for a current investigation to gain the best outcomes from I4A to leverage SOP.

This study examines the critical areas of I4.0 in India's manufacturing sector. The researcher's personal experiences and exposure to the local and international environment have led to choosing such a sensitive and need-of-hour topic for research. The systematic and extra-mile efforts will simplify the knowledge and concepts of I4.0 for the stakeholders' lucid, quick, and clear understanding so that its adoption journey becomes less cumbersome. This study has explained every critical aspect of the I4.0 vision, which could achieve productivity, sustainability, competitive edge, higher efficiency, cost reduction, waste control and efficient use of resources, error-free production, reduced or zero accidents, and higher value creation in business functionalities. The model developed in this study will help the industry to assess the preparedness and level of achievement of the I4.0 vision.

1.6.1 Research Aim

To assess the knowledge, understanding, and perception of the I4.0 and develop I4A, which will guide the decision makers to use the available resources, technologies, and concepts effectively to earn SOP. Manufacturing industries' experiences show that I4.0 has great potential to offer operational excellence in enhanced speed, flexibility, reliability, quality, and decreased cost like never before, even though few have adopted I4.0 techniques fully or partially (Wang, 2018). It uses cutting-edge technologies like the IoT, BDA, and specialized software solutions to seamlessly connect and control physical devices (i.e., smart machines, sensors, various devices, actuators, and equipment). The aim is to provide data-driven, innovative solutions to current and futuristic complex problems (Bajic et al., 2020). Additionally, extending automation and digitalization across the entire value chain will sustainably impact the whole value chain (Bhatia and Kumar, 2020). In this context, Indian Manufacturing industries are embracing digitalization and smart practices aggressively with the guidance and support of the Indian government through various schemes, having realized the immense potential of I4.0 to transform industrial operations into smart and sustainable operations. Thus, this study is an effort to provide the empirical framework for I4A to assess the SOP to help practitioners, decision-makers, and researchers work out amicable solutions to accelerate the I4A in emerging nations such as India, missing in the earlier studies. Thus, to address the mentioned issue, the following research objectives and questions are derived:

1.6.2 Research Questions

- Are Indian manufacturing industries aware of the I4.0 vision?
- What are the crucial factors and crucial constructs impacting the I4.0 progression in the manufacturing industries of India?
- What is the direct and indirect impact of I4A on SOP?
- How do we develop and validate a sustainable model for I4A to earn sustainability and a competitive edge in the volatile market?
- What constitutes a feasible and viable I4A model?

1.6.3 Research Objective

- To understand the I4.0 perception and status in the Indian manufacturing industrial context.
- To identify and understand the factors and crucial constructs impacting I4.0 progression in Indian manufacturing industries.
- To assess and evaluate the direct and indirect impact of I4A on SOP.
- To design the I4A model to prescribe the way forward for industries to earn a competitive edge in the volatile market.

- To endorse and validate the SMART PLS model through expert group and literature review.

1.6.4 Scope of Research

I4A is the need for an hour. Every sector must take the necessary initiatives to create the right combinations of skills, technologies, and infrastructural support to set the precedence for companies. Even if this is true, the academic research to support real-world applications comprehensively lacks momentum (Rampedi and Schoeman, 2021). In the first stage, the study identified the I4.0 KPI and KSF, as well as KPIs and I4.0 risk, and then further assessed and evaluated the interrelationships between them through exploratory case studies where the role of LR and experts were crucial. After that, the study sought to construct a solid model using suitable apt multicriteria decision-making methods (MCDM) to promote organizational sustainability.

A survey is also conducted in order to devise a model to examine the interaction between I4A, DC, CEP, and SOP. The findings of this research are statistically confirmed using structural equation modeling techniques (SEM), with the use of real-time software programs Smart PLS 3.0 and SPSS v 23. The model has left no scope for systematic errors, as it followed a triangulation approach to validate the inputs at every stage. The mixed method approach followed in this study confirms this. The most updated and effective software package versions were used, which increased the validity of the study's findings.

The government has acknowledged on various platforms that Indian companies must adopt new technologies and take advantage of government policies and significant infrastructure to produce world-class products. Proper synchronization between the government and industry bodies will push the common agenda faster (Jacobs and Pretorius, 2020). Thus, this study has made a holistic effort to provide a focused and inclusive model of I4A, which will set the pace and give clarity about the roles and responsibilities of each resource. Digital leadership and effective change management conducive to sustained growth should be one of the priorities of companies (Skhephe et al., 2020). Although the government is providing the direction, it appears that the recommendations have not, to date, translated into actions, mainly because of missing risk assessments. Therefore, this study is relevant to all sectors, providing guidelines and direction to their strategists and policymakers to integrate the I4.0 practices.

Therefore, this study's need to design and develop an I4A model is highly relevant and essential.

Hence considering the above manifesto, the significant results obtained from the exploratory study ranking I4.0 KSF considering the I4.0 KPIs is that the internet network infrastructure and present I4.0 technological status are the most critical success factors in the I4A domain. According to study results, reliable internet infrastructure, low latency, and seamless connectivity are all essential for the I4A's effectiveness. I4.0 practitioners and policymakers could create a roadmap and a strategic plan for its implementation with the help of priority ranking. The study advises manufacturing industrial organizations to develop efficient policies and plans to implement I4.0, enhancing the business's performance.

According to the investigation of the exploratory study of rating I4.0 risks according to I4.0 KPIs, information security and cost are the most significant cause-and-effect KPIs. Additionally, it has been discovered that I4A's decision-making procedure gives serious consideration to concerns about both technological and societal risks. By reducing the adverse perception of I4.0 implementation efforts due to barriers and risks and reducing the effect of the COVID-19 pandemic on India's manufacturing industries, this study will assist managers, advisors, engineers, and policymakers in enhancing the organization's overall performance. This study's succinct yet simple model significantly contributes to new information that abstractly addresses the I4.0 vision's more comprehensive range. As the first of its kind, this highlights the research's uniqueness.

The association between I4A, DC, CEP, and SOP is tested empirically in this remarkable study examining the relationship between I4A, DC, CEP, and SOP. The study is grounded in the theory of contingency and dynamic capability (DCV). The study's primary finding was that I4A drivers are positively associated with I4A. Positive interactions between DC and DC drivers are also present. The link between CEP and CEP drivers is also favorable, except for the driver circular dynamic environment (CDE). Furthermore, a promising connection between I4A and DC, DC and CEP, CEP and SOP, and I4A and SOP is confirmed. Additionally, the research draws an incredibly interesting outcome: DC and CEP integration is a key mediating construct that positively mediates the link between I4A and SOP.

The proper conclusions and approaches to I4A will also be of interest to the decision-makers aiming to boost and restore the companies' faith in I4A. This study has identified the prominent I4.0 KSFs, KPIs, risks, prominent constructs, subconstructs, and items after a detailed discussion with experts and SLR. According to the researcher, the developed models will serve as a roadmap for businesses, entrepreneurs, governments, and consulting firms as they create effective KSFs and I4.0 risk management plans for underdeveloped nations. Also, the insights obtained through investigating the relationship among I4A, DC, CEP, and SOP have tried to provide one of the essential contributions to leveraging the performance of an organization. As a result, this study significantly contributes to the new body of literature, has the potential to accelerate I4A, and will help industries become sustainable in a globally competitive business climate by improving their SOP.

1.7 Research Approach

The methodology employed to carry out the goals and objectives of the study and respond to the earlier formulated research questions at the beginning of this chapter in **Section 1.7** is briefly outlined further in this section. For this study, an exploratory case study strategy and a survey approach for data collection from manufacturing companies in India were designed as part of a mixed-method approach. Thus, the research strategy and steps taken to carry out the current study are shown in **Figure 1.3.** The following subsections elaborate on a summary of the procedures used in this research.

1.7.1 Literature Review and Experts Intervention Leading to Outlining the Objectives and Research Questions of the Study

A current LR of the rapidly expanding and intensely interdisciplinary I4.0 research domain is provided, along with the role of experts in the I4.0 domain in this section. It presents a quantitative literature assessment of the I4.0 field in addition to the findings of a qualitative investigation. Together with aspects affecting I4A, its benefits, enabling technologies, problems, and opportunities, the study themes pertaining to I4.0 in its manifestation are also explored. In this research, quantitative analysis was carried out utilizing a data-driven technique that combined bibliometric analysis and qualitative analysis using SLR methodology. Three significant additions to the body of literature on I4.0 have come from the LR. First, it offers a comprehensive overview of this subject using well-known study fields, top research subjects, authors, nations, and publications with a multitude of citations. Secondly, it reveals the methodological approach and trend analysis of the key themes and topics based on synthesizing results from the bibliometric analysis. Finally, the results of the quantitative LR using the SLR methodology show how a systematic approach was utilized to describe the particular issue and how crucial the identified constructs are in actual modeling in the present study. Further, the expert's insightful contribution in finalizing the I4.0 KSFs, KSFs, and risks, important constructs I4A, DC, and CEP, as well as their drivers, along with this phase to seek and identify the proper research gap yields the appropriate tools and methods identification to address the issue examined for the proposed investigation.

1.7.2 A Plan for Exploratory Case Studies

The primary objective of using the exploratory case studies approach in this study is to understand how Indian manufacturing companies perceive the I4.0 paradigm and how they are devising strategies to deal with the disruptive transformations happening due to the emergence of I4.0. The exploratory case study objectives, design, procedure, questionnaire development, case analysis strategy, and presentation of case findings are included in a thorough plan for conducting exploratory case studies. The information from case studies is gathered through a semi-structured questionnaire, interview sessions, plant visits whenever possible, and internal company records if the company permits. When collecting qualitative data, a semi-structured questionnaire is employed, allowing space for the interviewer to incorporate more pertinent information as it becomes available. Expert selection in the focus group followed a process to ensure the right combination of I4.0-related expertise and experience. The active engagement with the focus group helped the research in multiple ways, though it was challenging and limited due to the COVID-19 pandemic. The exploratory case studies' findings are used to develop the conceptual framework and study hypotheses for the current analysis.

1.7.3 Designing Survey Instruments and Conducting a Survey

An outcome of exploratory case studies leads to conceptual framework development and hypothesis formulation, further adding to experts' interventions and the comprehensive LR converge in devising the survey instrument development. During the pilot testing phase, the academics and practitioners in the field of I4.0 and digitalization provided feedback and expert opinions on the questionnaire items, which helped to enhance and fine-tune the survey instrument's quality. Indian manufacturers work in a variety of sectors, along with the automotive industry, metals and machinery, electrical and electronic equipment, energy, information technology, furniture manufacturing, defense/aerospace equipment manufacturing, food and beverage manufacturing, and plastics manufacturing are offered a structured survey questionnaire. As a result of the respondents' exposure to I4A, DC, CEP, and SOP phenomena, study respondents were identified using purposive random snowball sampling approaches. The most appropriate sampling method is a purposive random sample since it ensures that each participant has a chance of reaching the sample frame in the given circumstances. This approach was taken into consideration for the study because random sampling entails selecting a specific number of people who will engage in it from the pool of potential participants (Aliabadi, V., Ataei and Gholamrezai, 2021). In order to make sure that the proper information passes through the targeted respondents, it has been established that they hold prominent positions in the organizational hierarchy. The study gained a great deal from the contributions of experts who were identified as CEOs, CFOs, COOs, directors, general managers, senior managers, and managers to gain insights into I4.0.

1.7.4 Synthesis of Survey Data and Presentation of Assessment Outcomes

Before undertaking data analysis, the qualitative and quantitative data used in this study are thoroughly evaluated. Every attempt is taken to maintain the data's value, context, and sentiments during the data cleaning process. Even though much of the data was already in place and only a little work was needed to prepare it for analysis, measures were taken throughout the preparation stage to ensure that only pertinent data was received. Due to data privacy and other pretexts, the experts declined to allow audio or video recordings. The primary objective of the mixed approach was to identify, correct, process, and eliminate any anomalies that may have occurred when the responder was filling out the response sheet either purposefully or accidentally. The data is then suitably classified by creating relevant coding to give the data analysis the proper meaning and comprehension. Finally, a preliminary descriptive analysis of the survey is conducted by carefully reviewing and summarizing the valid responses. The survey findings are produced using the appropriate mathematical instruments and the statistical analysis programs SPSS v23 and SmartPLS 3.0.

1.7.5 Development of Operational Framework and Way Forward

The framework developed is based on exploratory case studies, surveys, and LR results. Initially, the framework comprises I4.0 KPIs, KSFs, and risks. Also, the study's proposed robust integrated operational framework systematically addresses the I4A, DC, CEP, and SOP phenomena and provides a systematic path for the I4.0 vision's sustainable realization. The model aims to create a path to creating an ecosystem that will support cutting-edge technologies. I4.0 technologies-compliant infrastructure, training, and development facilities, strengthening inherent capabilities, customized yet progressive policies, and optimum resource utilization. The results of this study will ultimately enable a thorough and cautious approach to implementing I4.0, satisfying stakeholder needs, and becoming ready for disruptive global competition to reach SOP for gaining a competitive advantage

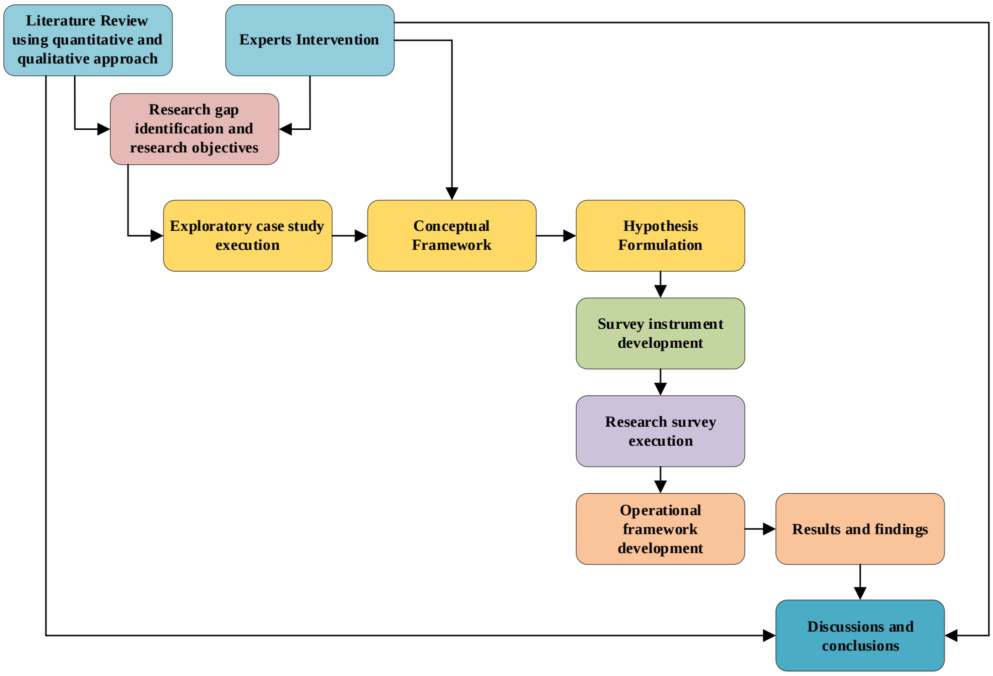

Figure 1.3: Research Approach

1.8 Outline of the Thesis

The thesis is organized into seven chapters overall.

1.8.1 Chapter 1 Introduction

Chapter 1 establishes the urgency and importance of the I4.0 agenda by clearly articulating the background. The prevailing scenario and increasing pressure from outside the world are forcing businesses to think of effective integration of available resources to build a better manufacturing system. The strategists are expected to be innovative in building collaboration while ensuring organizational sustainability at the top. The chapter further encompasses a brief on the problem statement, rationale, and significance of the study in today's context. It aligns with the agenda to meet the research gap by adopting the I4.0 vision. Next, the chapter outlines the research aims, objectives, questions, and approaches used to accomplish the objectives. This chapter lastly presents the outline of all the chapters in the thesis.

1.8.2 Chapter 2 Literature Review

Chapter 2 provides a macro and micro-level literature overview of the I4.0 realm to highlight research potential in this area and pinpoint themes that require further research. An in-depth overview of I4.0 research and manifestation efforts are provided through a comprehensive literature study that includes quantitative and qualitative analysis of I4.0. The second chapter discusses the introduction of the fourth-generation industrial revolutions, the state of knowledge in I4.0, and research themes. After a literature review to finalize the study's constructs, underlying theories, tools, and techniques used in previous studies in context to I4.0 are reviewed, and finally, research gaps are identified. This chapter also lists a few I4.0-related initiatives implemented globally over the past decade. After that, it talks about how manufacturing companies in India might benefit from I4.0, new initiatives that the government has launched, I4.0, and the advantages of implementing cutting-edge technology.

The corpus of literature on I4.0 has benefited significantly from contributions given by the quantitative literature review. In the beginning, it gives a complete overview of this topic by listing well-known research fields, top research subjects, authors, nations, and publications that have received a lot of citations. Based on an assessment of the bibliometric study's findings, a trend analysis of the main concerns and themes and the study's methodology is also revealed. The results of the SLR-based qualitative analysis demonstrate how a methodical approach was used to explain the specific problem and how important the found constructs were for developing the study's model. Further, it extends to identify the research gap in the I4.0 domain that exists in the Indian setting.

1.8.3 Chapter 3 Research Methodology

The approach used to conduct the current study is the primary concern of chapter 3. Various research methodologies are employed, including surveys, semi-structured interviews, and exploratory case studies. This chapter discusses the design of exploratory case studies, exploratory case analysis procedures, survey questionnaire formulation, questionnaire pre-testing through a pilot study, sampling procedure, data collection methods, and data analysis strategies. The conceptual framework for measuring SOP through contributing factors I4A, DC, and CEP is established following a literature study and a systematic investigation of the study problem undertaken. Specific hypotheses are developed further for testing a hypothesis.

1.8.4 Chapter 4 Key Success Factors Assessment for I4.0 Adoption in the Indian Manufacturing Industry.

Chapter 4 included the introduction of the exploratory case study considered for the current research. Further, it discusses the LR, research methodology for KPIs and KSFs identification, and research tool alternatives prioritization using Evaluation based on Distance from Average Solution (EDAS) selection to assess the developed model. Following the elaboration on the developed model for KSFs assessment impacting I4A in Indian manufacturing along with the profile of the experts involved in this study, data collection process, and validation. After that, the application of the EDAS method to the research problem is discussed and further concluded with the research findings discussions and study implications.

The main goal of this chapter is to further this study to assess the relevance of I4.0 KPIs and rank I4.0 KSFs to simplify I4A in Indian manufacturing organizations. The study’s findings show that among the considered eleven KSFs, the internet network infrastructure is the most important. The next most important KSF to address is the current technological state related to I4.0, which was chosen and assessed using EDAS. This chapter suggests that seamless connectivity and high-speed internet network infrastructure are necessary for the deployment of I4.0 practices to be successful.

1.8.5 Chapter 5 Development of an Integrated Framework for Risk Assessment for Industry 4.0 Implementation in the Manufacturing Industry

This chapter included the introduction of the exploratory case study considered for the current research. It discusses the introduction, LR, and research methodology, including the KPIs and I4.0 risks identification, along with the apt MCDM methods selected for assessing the study's problem. Further, it explains the application of integrated DEMATEL-CRITIC- MABAC, PROMEETHEE II, MOORA, and COPRAS methodology followed by the results and discussions, study implications including theoretical, managerial, and Post COVID-19 Pandemic Scenario. Finally, describe the conclusion of the study.

Out of all the KPIs, this study has shown that information security and cost require attention which is the findings of DEMATEL-CRITIC methods. The most crucial risks on the options list were technological and social, which need to be addressed immediately and confirmed using MCDM techniques, including MABAC, PROMEETHEE II, MOORA, and COPRAS. Thus, to provide policymakers, researchers, and business employees guidelines for the decision-making process to adopt I4.0 practices in their firms, the study in-depth addressed the elements impacting risks, contributing to I4.0, and risk prioritization.

1.8.6 Chapter 6 Survey Data Interpretation and Results Analysis

The results of the survey are described and analyzed in this chapter. The background of the organizations involved and survey observations are presented before evaluating the results. The chapter also includes demographic profile facts for the responders. Additionally, it demonstrates the uses of software packages SPSS v23 and SmartPLS 3.0 to analyze the path model of the developed framework and statistical analysis for evaluating SOP while considering the effects of I4A, DC, and CEP addressing Indian manufacturing industries. Further, a mathematical model is developed to predict the SOP using I4A, DC, and CEP. A framework for SOP measurement is grounded on LR, the results of exploratory case studies, and survey data. Finally, the findings and recommendations elaborated on the developed framework will help researchers, managers, practitioners, decision-makers, and policymakers devise the organizational strategies for deploying I4A, DC, and CEP to achieve SOP to attain competitive advantage.

1.8.7 Chapter 7 Discussions, Study Implications, and Conclusion

This chapter comprises a critical assessment, discussion, and deliberation of the research findings. Reference is made to past studies which agreed or disagreed with the findings. This chapter provides a comprehensive discussion on each I4.0 KPIs, KSFs, and the risks with the final model developed to investigate the insights into the relationship of I4A, DC, CEP, and SOP. It critically evaluates the role of these three crucial constructs in creating organizational sustainability through enhancing SOP.

The chapter illustrates the net takeaway from the research and makes well-grounded and contextualized recommendations based on the research findings. Most critical constructs are identified, and their importance is quantified. This chapter proposes the solutions for successful I4A by recommending the solutions and way forward.

2 Literature Review

2.1 Introduction

This chapter explores existing literature on I4.0 technologies, success stories, practices, barriers, and enablers. The technology mix is driving the larger agenda of creating a digital and conducive ecosystem for the adoption of the I4.0 vision. In this evolution process, identifying the gap between existing and proposed capacity is the first important step. This chapter first systematically explored the critical dimensions to comprehend the width and breadth of the problem. Many studies have been referred to before finalizing the research tools to investigate the problem's critical dimensions (constructs). Existing literature has already studied and found an impact on the company's perception of I4.0 practices, though in a minimal environment. Organizations have realized that leadership, change management, and upskilling are key to full-fledged technology adoption and cannot be studied in isolation (Alonso-Almedia and Llach, 2019). Hence, the need for a comprehensive study to explore both phenomena is evident.

This study has adopted an integrated approach at every stage to make it most reliable and feasible in real-world situations. Leaders, decision-makers, and researchers can adopt this research's findings and further develop them in different contexts. Leaders should also be mindful of the increasing percentage of millennials in companies and their unique behavior patterns and learnability. Worldwide labor statistics revealed that till 2018 they made up 50%, and by 2025, it will grow to 75% of the workforce. The United States is one of those countries where the young generation is the largest in the workforce (Dieffenderfer and Watts, 2020). This necessitates the urgent shift toward agile, innovative, and flexible cultures that will instill the urgency to adopt emerging technology solutions (Badri and Wai, 2021; Russell Calk and Patrick, 2017).

2.2 Literature Review Methodology

The research studies in the I4.0 realm are multidisciplinary and have shown enormous growth in published articles over the past few years. The absence of comprehensive and systematic reviews persists despite the rapid evolution of this field. As a result, this research entails a thorough analysis and synthesis of a broad array of I4.0 paradigms.

As depicted in **Figure 2.1,** existing I4.0 relevant literature was reviewed using both quantitative and qualitative analysis techniques.

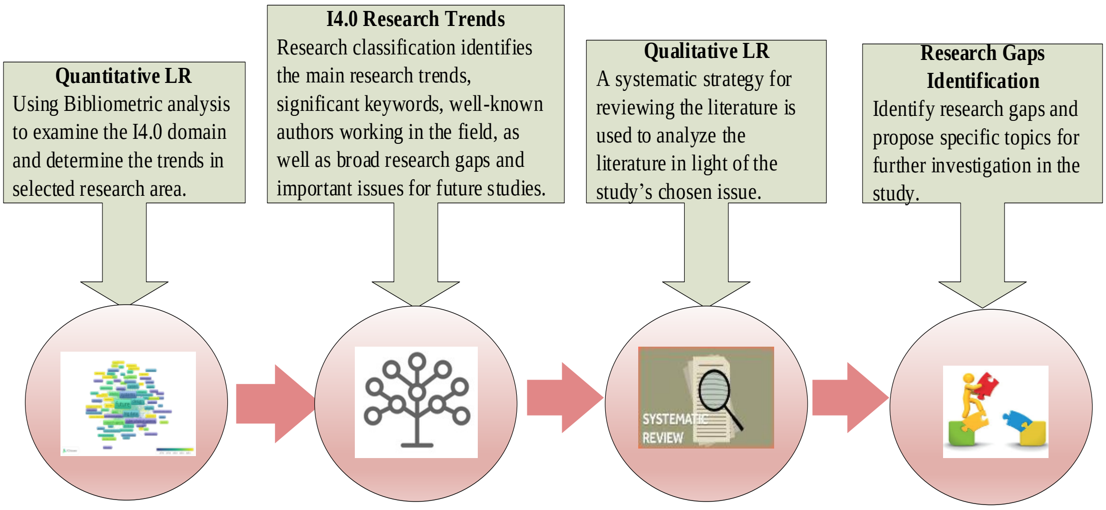

Figure 2.1: Process followed for Literature Review

2.2.1 Bibliometric Analysis

This section examines and summarizes I4.0 literature using quantitative assessment based on bibliometric analysis to demonstrate the emerging research pattern in an attempt to demystify this domain. The use of such a data-driven approach is justified since it minimizes biases in analysis and reveals areas of research that would not be readily apparent through more conventional techniques of examining literature. The current study examines the quantitative literature review's three research questions below.

Q.1 What are the primary research themes and dominant trends in the I4.0 research domain?

Q.2 What changes can be seen in the I4.0 research domain over time?

Q.3 How closely do the critical research trends semantically relate to the research areas?

The method chosen to accomplish the objectives of the quantitative literature review of this study is a bibliometric analysis because it aids in tracking the development of a specific topic. It introduces a visible and reproducible review process by implementing a quantitative methodology to present, assess, and monitor a research field. The general information for this bibliometric performance assessment was collected using the database Web of Science (WoS) Core Collection, which includes a number of indexes, including the Social Sciences Citation Index, the Science Citation Index Expanded, the Conference Proceedings Citation Index, the Emerging Sources Citation Index, and the Social Sciences & Humanities and, among many others. A simple search was done on the query "Industry 4.0 (Title) AND 2011-2021 (All Fields)". After retrieving 4547 publications in the first instance, it was decided to narrow the findings by utilizing data cleaning to eliminate duplicate items. Thus, 4239 documents made up the final dataset. The information was evaluated to determine document types, source origin, language, topic matters, annual growth, keywords, countries, citations, authorships, and references. The extant literature review search outcomes using both WoS and software VOSviewer were expressed in frequency and percentage while presenting data for yearly growth, co-occurrence, authorship, citation, source analysis, frequency, and link strength, for each document obtained in a particular year. The outcome of the WoS analysis is elaborated as expressed in the next section.

2.2.1.1.1 Yearly Progress in Publications, Document Types, and Research Subject area

It is observed from the analysis that in 2012, Hofmann et al. (2012) conducted the first study on I4.0 in a paper titled "Smartphone Green Vision at Dawn of Industry 4.0." The number of the associated articles then gradually increased between 2013 (7) and 2021(1094). It was dramatically raised over a short time, as depicted in **Figure 2.2**; it is anticipated that there will be more publications in 2022 than in 2021. It is observed from the WoS database that many of them are already on the schedule.

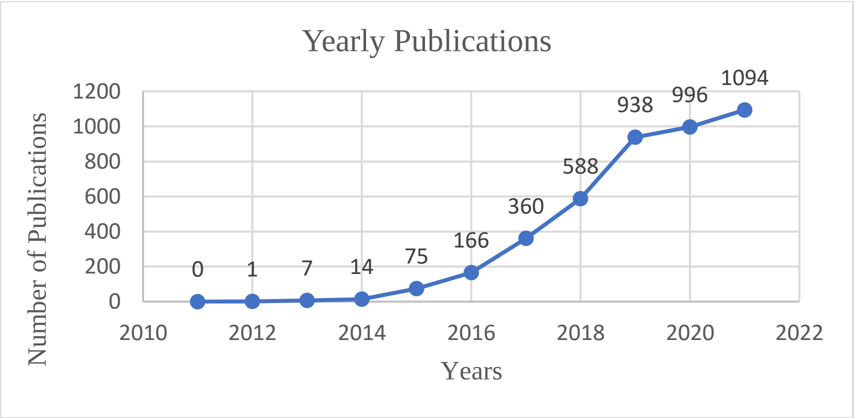

Figure 2.2: Figure Yearly Publication Progress

2.2.1.1.2 Document Types

This study has identified the most prominent preferred nine documents type, as shown in **Table 2.1** of published papers in the I4.0 domain. It is observed that the maximum contribution is of the article category (44.46 %), followed by conference proceedings papers (35.50 %), and the rest, as shown in **Table 2.1**.

Table 2.1: Types of Documents and their Proportion

Document Type	**Frequency**	**Percentage**
Article	1,885	44.46
Conference Proceeding Paper	1,505	35.50
Review	266	6.27
Editorial Material	260	6.13
Short Survey	150	3.53
Articles in press	70	1.65
Book Review	50	1.17
Data Paper	32	0.75
Book Chapters	21	0.04

2.2.1.1.3 Research Subject Area

In this study, 133 research subject areas were identified, out of which the top 20 research subject areas are stated in **Table 2.2**. The majority of studies on I4.0 were in the area of Industrial Engineering, followed by Engineering manufacturing, Engineering electrical and electronics, and management as per the priority shown in **Table 2.2.** The results obtained from the VOSviewer analysis are expressed below.

Table 2.2: Research Subject Area

S N	**Research Subject Area**
1	Engineering Industrial
2	Engineering Manufacturing
3	Engineering Electrical Electronic
4	Management
5	Computer Science Information Systems
6	Automation Control Systems
7	Computer Science Theory Methods
8	Computer Science and Interdisciplinary Applications
9	Operations Research Management Science

S N	Research Subject Area
10	Business Models
11	Engineering Multidisciplinary
12	Computer Science Artificial Intelligence
13	Telecommunications
14	Green Sustainable Science Technology
15	Economics
16	Environmental Sciences
17	Materials Science Multidisciplinary
18	Environmental Studies
19	Engineering Mechanical
20	Robotics

2.2.1.1.4 Keyword Analysis

Bibliometric maps can be created and visualized using the software program VOSviewer, which was used to map the keywords in this study. **Figure 2.3** displays a keyword map created using bibliographic data obtained by reading a file from the WoS bibliographic database using cooccurrence and keyword plus combinations. In order to determine the most important keywords for the search, a minimum of 20 keyword occurrences is initially taken into account, which indicates that only those keywords taken into account have appeared at least 20 times in the documents considered. This criterion was met by 84 of the detected keywords. Color, frame size, font size, and line thickness were employed in a map visualization of the keywords to show how they relate to one another. Examples include the grouping of keywords with the same color. Therefore, in this study, terms like “technologies,” “barriers,” “capabilities,” “circular economy,” “digital twin,” “decision making,” “big data analytics,” and “logistics,” etc. share a similar color. It is represented through yellow frames and lines, indicating that these terms are closely related and frequently co-occur. **Table 2.3** shows the identified most commonly used keywords with their frequency of occurrence and link strength.

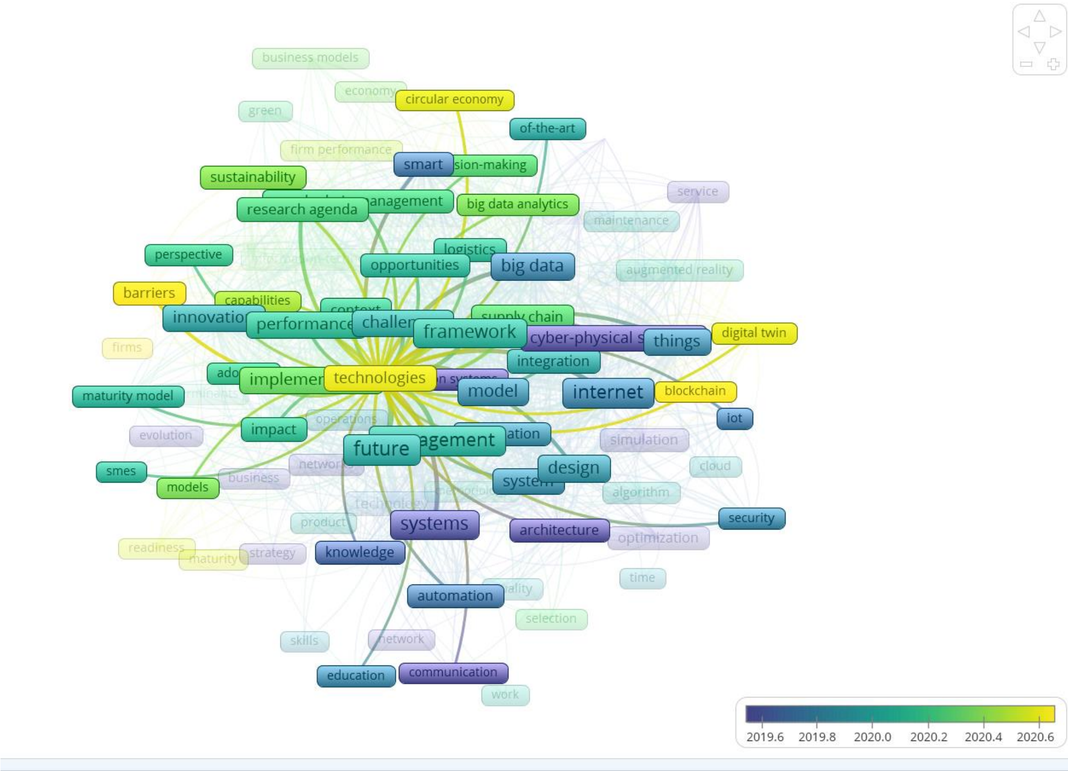

Figure 2.3: Mapping of Keywords

Table 2.3: Identified Most Commonly used Keywords

SN	Keyword	Frequency of Occurrences	Total Link Strength	SN	Keyword	Frequency of Occurrences	Total Link Strength	SN	Keyword
1	future	437	1776	31	adoption	52	257	61	readiness
2	internet of things	362	1427	32	automation	58	250	62	manufacturing systems
3	management	314	1314	33	horizontal integration	48	234	63	operations
4	framework	283	1174	34	knowledge	61	221	64	capabilities
5	digital manufacturing	243	1138	35	architecture	57	219	65	green
6	challenges	187	905	36	industrial internet of things	53	203	66	artificial intelligence
7	digitalization	191	848	37	simulation	62	194	67	lean production
8	predictive maintenance	231	819	38	digital twin	43	189	68	quality
9	smart manufacturing	277	819	39	analytics	44	188	69	models

SN	Keyword	Frequency of Occurrences	Total Link Strength	SN	Keyword	Frequency of Occurrences	Total Link Strength	SN	Keyword
10	implementation	164	745	40	production systems	40	184	70	support
11	design	228	736	41	security	48	183	71	SMEs
12	technologies	156	711	42	optimization	69	175	72	economy
13	innovation	164	653	43	virtual reality	45	174	73	selection
14	performance	172	617	44	service	41	172	74	maturity
15	research agenda	98	565	45	perspective	34	166	75	education
16	cyber-physical systems	125	563	46	maturity model	43	157	76	determinants
17	cloud computing	100	516	47	methodolog y	32	140	77	firms
18	intelligent manufacturing	148	499	48	circular economy	26	138	78	communicati on
19	systems	98	495	49	information-technology	34	138	79	strategy
20	context	104	460	50	decision-making	33	127	80	evolution
21	integration	92	421	51	cloud management	28	124	81	network
22	augmented reality	101	420	52	strategies	29	124	82	time
23	opportunities	73	400	53	algorithm	39	122	83	skills
24	impact	95	375	54	blockchain	24	121	84	work
25	supply chain management	61	316	55	firm performance	28	121		
26	information	71	313	56	product	25	118		
27	logistics	62	297	57	maintenance	29	112		
28	sustainability	62	290	58	networks	40	111		
29	barriers	56	282	59	business	28	106		
30	big data analytics	54	269	60	business models	20	106		

2.2.1.1.5 Countries Contribution

Countries' contribution, in combination with co-authorship, is derived from the VOSviewer. The number of documents per country and citations per country are selected at least five. These criteria fetch 75 countries that have a strong co-authorship relationship with other countries. **Figure 2.4** shows that Germany has the highest number of citations and documents, as its frame size is bigger than others. At the same time, **Table 2.4** reflected the less strong co-authorship relation with other countries compared to the United Kingdom. The analysis can be displayed in detail in **Figure 2.4 and Table 2.4** below.

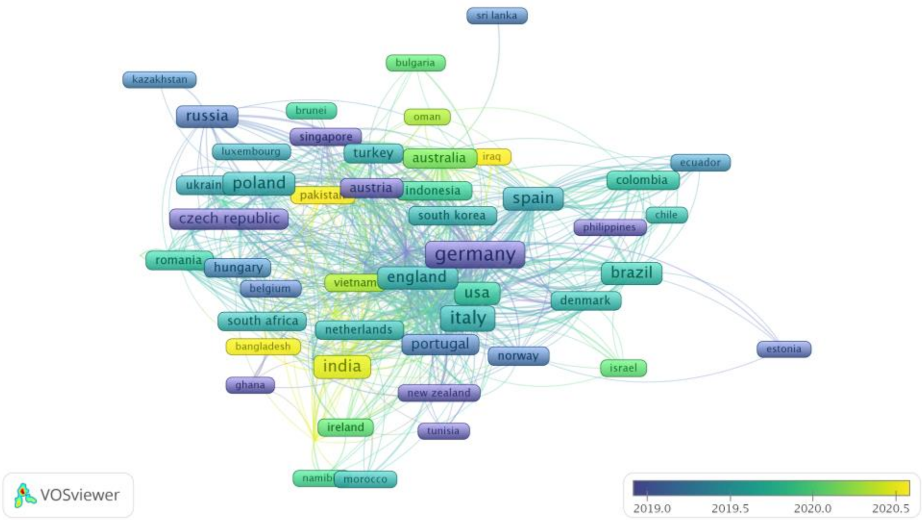

Figure 2.4: Mapping of Co-authorship with Countries

Table 2.4: Identified Significant Countries with the Prioritized Link Strength

SN	Country	Documents	Citations	Total Link Strength	SN	Country	Documents	Citations	Total Link Strength
1	United Kingdom	245	8860	300	41	Serbia	44	389	28
2	Germany	554	14905	266	42	New Zealand	24	1921	27
3	USA	225	9607	261	43	Ukraine	40	206	26
4	China	246	8373	239	44	Vietnam	26	351	26
5	Italy	412	8883	232	45	Romania	55	481	25
6	India	256	6617	178	46	Egypt	12	319	23
7	France	155	5825	165	47	Japan	24	427	22
8	Spain	269	4301	162	48	Wales	18	670	21
9	Australia	102	1696	137	49	Croatia	23	298	19
10	brazil	243	6942	134	50	Thailand	28	365	19
11	Poland	261	2570	126	51	Slovenia	30	720	18
12	Malaysia	95	1597	96	52	Belgium	19	312	16
13	Sweden	83	2790	91	53	Ecuador	14	33	16
14	Portugal	146	2821	78	54	Venezuela	11	96	16
15	Canada	77	1719	77	55	Indonesia	49	215	15
16	Pakistan	39	650	70	56	Iraq	6	78	15
17	Austria	102	2147	67	57	Bangladesh	11	251	14

SN	Country	Documents	Citations	Total Link Strength	SN	Country	Documents	Citations	Total Link Strength
18	Taiwan	73	1877	59	58	Morocco	19	151	13
19	Finland	35	779	57	59	Chile	9	188	12
20	Saudi Arabia	34	807	56	60	Israel	14	273	12
21	Netherlands	41	604	49	61	Palestine	5	212	12
22	Russia	197	1678	49	62	Argentina	17	218	10
23	Scotland	33	667	49	63	Namibia	9	424	10
24	South Africa	77	1520	49	64	Ghana	5	215	9
25	Turkey	103	2113	46	65	Oman	6	57	9
26	Hungary	79	1259	45	66	Luxembourg	11	89	7
27	Mexico	47	942	43	67	Philippines	7	267	7
28	Norway	49	1174	40	68	Tunisia	6	161	7
29	Slovakia	126	738	39	69	Bosnia & Herceg	8	19	6
30	South Korea	49	694	39	70	Bulgaria	7	6	6
31	Colombia	50	460	38	71	Estonia	11	145	5
32	Greece	53	599	37	72	Brunei	5	25	4
33	Czech Republic	167	1661	36	73	Kazakhstan	8	21	3
34	United Arab Emirates	24	218	36	74	Latvia	9	8	3
35	Ireland	28	503	33	75	Srilanka	5	35	2
36	Switzerland	36	1109	33					
37	Singapore	25	538	32					
38	Iran	23	973	31					
39	Denmark	48	1126	30					
40	Lithuania	33	403	30					

2.2.1.1.6 Citation and Sources

The literature source contribution, in combination with the citation, is derived from the VOSviewer. For the search, a source is deemed to have ten minimum documents and citations. These criteria fetch 49 sources, as shown in **Figure 2.5. Figure 2.5 and Table 2.5** show that the Sustainability journal has the highest number of citations, documents, and link strength, as shown in its frame size, which is bigger than others. **Figure 2.5** and **Table 2.5** below show a detailed analysis of other sources.

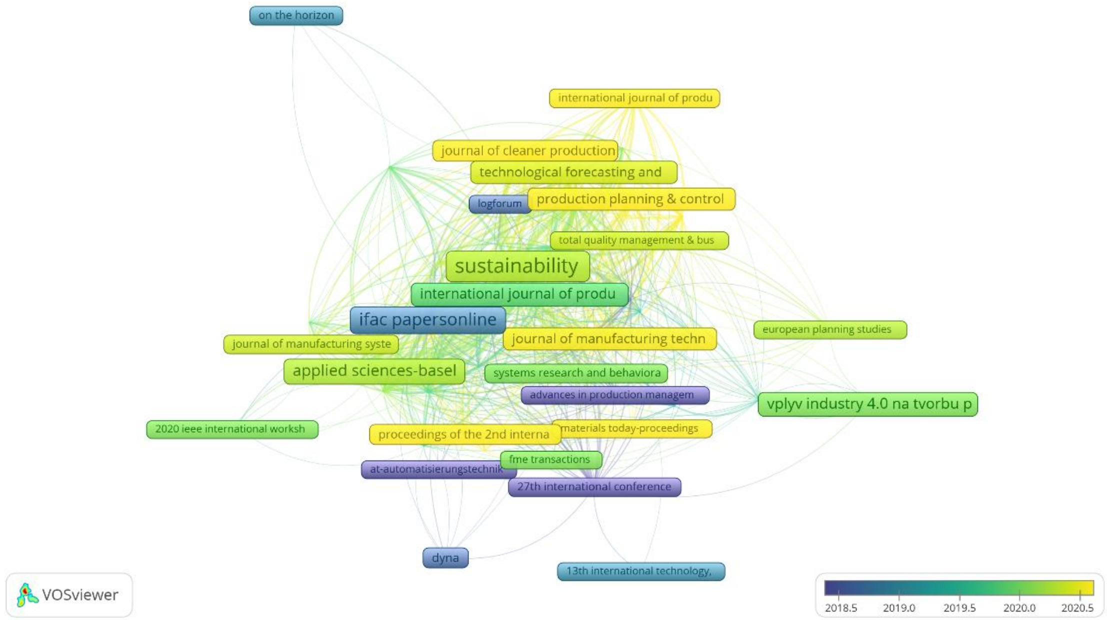

Figure 2.5: Mapping of Literature Source with Citation

Table 2.5: Identified Significant Sources with Citation

SN	Source	Documents	Citations	Total Link Strength
1	Sustainability	130	3040	1245
2	International Journal of production research	49	5842	1240
3	Technological forecasting and social change	39	2691	711
4	Computers in Industry	44	2912	648
5	Journal of cleaner production	34	1831	632
6	International Journal of production economics	27	2798	629
7	Journal of manufacturing technology management	38	1607	618
8	Production planning & control	37	1498	494
9	IFAC papers online	86	1792	390
10	Applied sciences-Basel	67	664	372
11	Benchmarking-an international journal	24	688	331
12	Computers & industrial engineering	26	1325	319
13	IEEE Access	54	2374	301
14	Sensors	40	735	215
15	International Journal of productivity and performance management	14	163	214
16	Energies	27	383	191
17	Manufacturing engineering society international conference 2017 (mesic 2017)	11	961	176

SN	Source	Documents	Citations	Total Link Strength
18	27th international conference on flexible automation and intelligent manufacturing, faim2017	16	988	171
19	Journal of intelligent manufacturing	20	1077	169
20	International Journal of advanced manufacturing technology	22	484	147
21	Journal of manufacturing systems	18	700	143
22	Processes	22	516	135
23	Systems research and behavioral science	16	240	131
24	IEEE transactions on engineering management	11	96	126
25	Management and production engineering review	14	317	114
26	Engineering applications of artificial intelligence	10	295	100
27	Social sciences-Basel	13	283	100
28	Total quality management & business excellence	10	171	93
29	Proceedings of the 2nd international conference on industry 4.0 and smart manufacturing (ism 2020)	22	74	86
30	International Journal of computer integrated manufacturing	16	172	82
31	Polish Journal of management studies	10	202	60
32	South African Journal of industrial engineering	12	130	55
33	IEEE transactions on industrial informatics	30	1234	54
34	Cybernetics and systems	10	179	52
35	Advances in production management systems: the path to intelligent, collaborative, and sustainable manufacturing	13	136	43
36	Enterprise information systems	11	295	40
37	European planning studies	11	178	33
38	Electronics	12	98	30
39	Log forum	10	91	30
40	FME transactions	12	53	29
41	vplyv industry 4.0 na tvorbu pracovnych miest 2019	56	13	29
42	Materials today-proceedings	10	101	26
43	vplyv industry 4.0 na tvorbu pracovnych miest	31	25	18
44	Dyna	24	35	11
45	At-automatisierungstechnik	11	84	9
46	2019 IEEE international workshop on metrology for industry 4.0 and internet of things (metroind4.0&iot)	10	67	8
47	On the horizon	14	68	6
48	2020 IEEE international workshop on metrology for industry 4.0 & IoT (metroind4.0&iot)	12	16	5
49	13th international technology, education, and development conference (inted2019)	11	11	3

2.2.1.1.7 *Citation and Authors*

The literature author's contribution, in combination with the citation, is derived from the VOSviewer. A minimum of five documents by a given author and five citations by that author are taken into account during the search. These criteria fetch 178 authors, as represented in **Figure 2.6. Figure 2.6** reflects that the author Zharinov, I. O. has a strong link with other authors, as shown in its frame size, which is bigger than others and shows more connecting links to other authors. Similarly, **Table 2.6** depicts the top 25 authors listed out of 178 and can be visualized based on documents, citations, and link strengths.

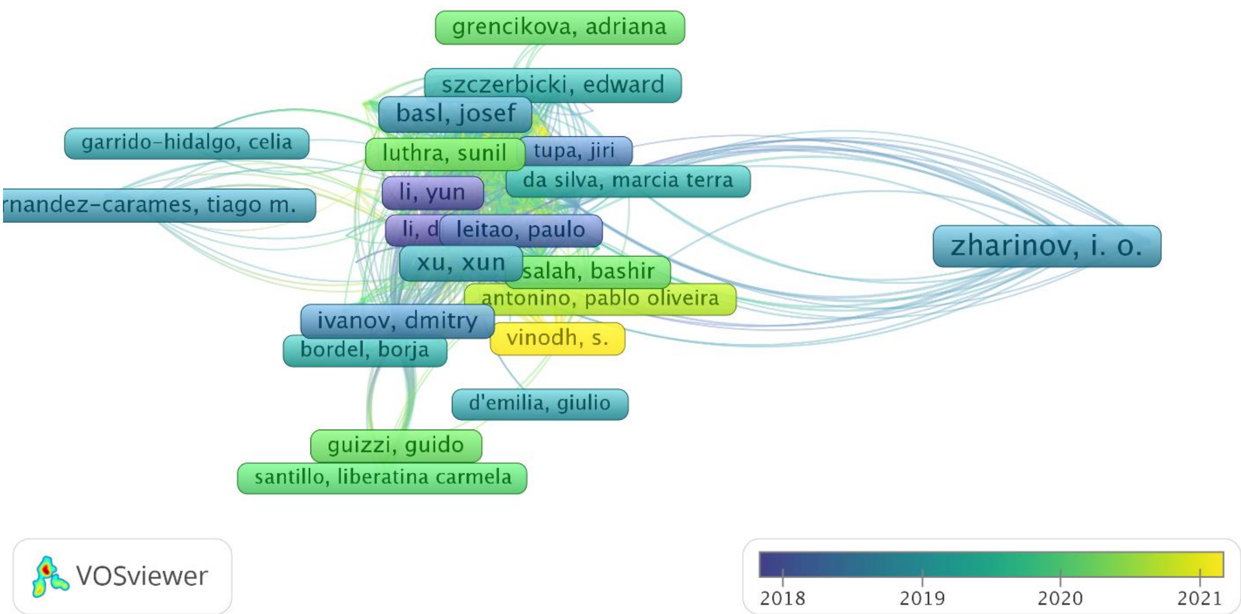

Figure 2.6: Mapping of an Author with Citation

Table 2.6: Identified Significant Authors with Citations

SN	Author	Documents	Citations	Total Link Strength
1	ghobakhloo, morteza	9	864	327
2	zharinov, i. o.	35	70	307
3	voigt, kai-ingo	10	1339	306
4	zakoldaev, d. a.	34	70	301
5	ayala, nestor fabian	5	1270	278

SN	Author	Documents	Citations	Total Link Strength
6	gunasekaran, angappa	10	897	277
7	shukalov, a. v.	28	67	277
8	luthra, sunil	8	688	262
9	garza-reyes, jose arturo	10	682	240
10	sony, michael	8	424	240
11	li, ling	5	1464	226
12	xu, li da	9	1462	222
13	xu, xun	14	1612	222
14	mueller, julian marius	8	857	219
15	orzes, guido	7	512	213
16	benitez, guilherme brittes	5	673	210
17	mangla, sachin kumar	7	681	209
18	kamble, sachin s.	5	713	202
19	deschamps, fernando	8	786	197
20	kumar, anil	8	258	194
21	mueller, julian m.	10	652	194
22	wan, jiafu	8	1841	192
23	ivanov, dmitry	12	1507	191
24	tortorella, guilherme luz	7	587	189
25	zhong, ray y.	9	1376	181

2.2.1.1.8 Citation and Author Documents

The author documents contributions, in combination with citations, derived from the VOSviewer.The minimum number of citations of the document is considered 100 for the search. These criteria fetch 158 documents of authors, as depicted in **Figure 2.7.** **Figure 2.7** shows that the author Lasi (2014) has a strong link with other documents, as shown in its frame size, which is bigger than others and shows more connecting links to other authors' documents. Simultaneously, **Table 2.7** shows the top 30 authors' documents listed out of 158 based on link strength and can be visualized based on citations and link strengths.

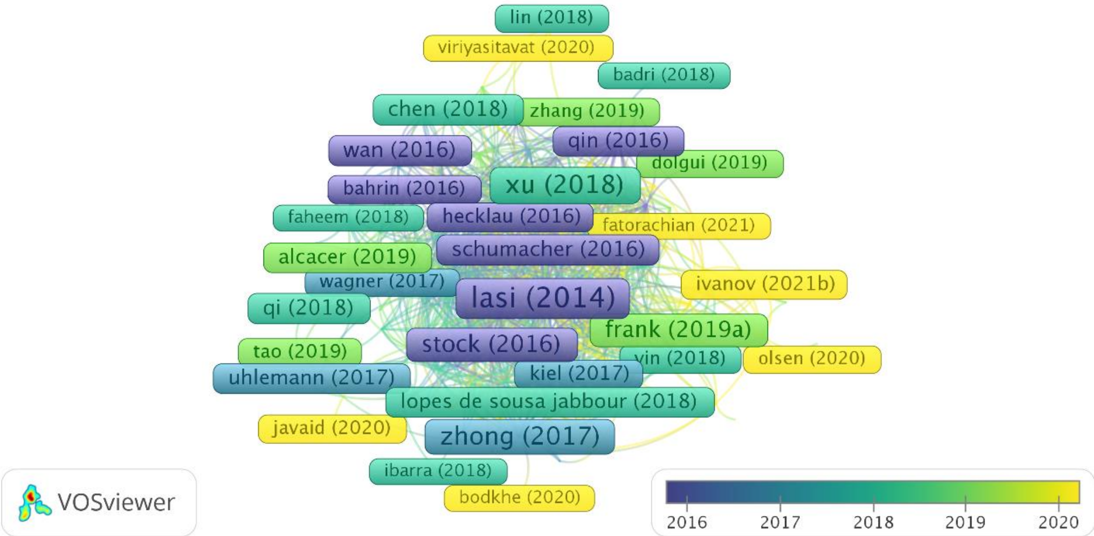

Figure 2.7: Mapping of the Author Documents with Citation

Table 2.7: Identified Top 30 Author Documents based on Link Strength

SN	Document	Citations	Links
1	Lasi (2014)	1671	47
2	Ghobakhloo (2020)	262	42
3	Liao (2017)	750	40
4	Haleem (2019)	117	38
5	Lu (2017)	694	38
6	Stock (2016)	714	36
7	Culot (2020)	136	36
8	Xu (2018)	1044	34
9	Moktadir (2018)	134	32
10	Hofmann (2017)	641	32
11	Ghobakhloo (2018)	400	29
12	Beier (2020)	113	29
13	Lee (2014)	833	29
14	Qin (2016)	371	27
15	Frank (2019)	635	27
16	Mueller (2018)	354	26
17	Piccarozzi (2018)	182	26
18	Dalenogare (2018)	491	24
19	Raj (2020)	197	24
20	Thuy Duong Oesterreich (2016)	474	24
21	Jabbour (2018)	316	24
22	Oztemel (2020)	487	24
23	Ivanov (2016)	271	24
24	Muhuri (2019)	172	23

SN	Document	Citations	Links
25	Kamble (2018)	398	23
26	Luthra (2018)	268	22
27	Wang (2016)	608	22
28	Ghobakhloo (2020)	108	22
29	Kamble (2018)	216	21
30	Zhou (2015)	354	21

2.2.2 Qualitative Literature Review

The qualitative literature review utilizes and accumulates a variety of empirical materials, such as case studies, actual first-hand knowledge, personal experiences, interviews, data related to current advancements, and observation-based, chronological, interactive, and visual texts, to describe modern standards in the industry under consideration. Thus, to gain a deeper understanding of the topic under consideration, qualitative literature reviews employ a variety of interconnected interpretive methods. SLR is one of the techniques of qualitative literature review adopted in this study and described in the following section.

2.2.2.1 Systematic Literature Review Process

Systematic Literature Review (SLR) is chosen as the method of preference since it is a comprehensive and scientific way to perform a literature review. SLR assists in obtaining study findings that are transparent and replicable. Additionally, prejudice in the study's selection and inclusion for analysis is reduced by utilizing SLR. This research uses the SLR to thoroughly understand the I4.0, DC, and CEP drivers and their linkages to SOP from prior studies. This SLR led to an understanding of the topic under study and the necessary data to conduct this study (Tranfield et al., 2003). This practice ensures a structured, reproducible, and scientific process for accurately and impartially synthesizing and assessing the corpus of available knowledge (Tranfield et al., 2003). In this investigation, five stages were used to ensure the dependability and accuracy of the SLR process adopted. The first step in developing a research topic is to understand the study's scope and determine the goal of the investigation.

The second stage of the research was to find all pertinent literature that addressed the key ideas taken into account for the study to address the research topic. Hence, to maintain the literature review quality, the researcher chose the potential publications from the high impact factor, refereed journals. Research papers listed in the databases, such as “SCOPUS,” “Science Direct,” “Inderscience,” “EBSCO,” “IEEE,” “Web of Science,” “IEEE Xplore Digital Library,” “World Public Library,” and “Google Scholar,” published by prestigious publishers known for their high-quality publications, such as “Elsevier,” “IEEE,” “Wiley,” “Emerald,” “Springer,” and “Taylor and Francis,” have been considered as a reliable source of knowledge for the period from 2011 to February 2022. The following keywords were used to find the most relevant information and knowledge-related documents are, “Industrie 4.0”, “Industry 4.0 “, “Industry 4.0 Applications in Manufacturing”, “Industry 4.0 Barriers”, “Industry 4.0 Challenges”, “Industry 4.0 Drivers”, “Industry 4.0 Enablers”, “Industry 4.0 Inhibitors”, “Industry 4.0 Recognition”, “Industry 4.0 Risks Management”, “Industry 4.0 Success Factors”, “Industry 4.0 Technologies”, “Industry 4.0 Difficulties”, “Lean Manufacturing,” “Manufacturing Supply Chain,” “Industry 4.0 Readiness assessment”, “Green Manufacturing,” “Circular Economy,” “Circular Economy practices,” “ Dynamic Capabilities,” “COVID-19”, “Maturity Model,” “Multicriteria Decision Making Methods,” “Production and Manufacturing Supply Chain,” “Production Supply Chain,” “Risk Assessment Tools,” “Risk Management,” “Smart Factory,” “Sustainability,” “Sustainable Manufacturing,” “Industry 4.0 performance management”, “Industry 4.0 readiness assessment”, “Industry 4.0 implementation”. These keywords are further used to develop the themes using the Boolean operators AND and OR, while initially searching theme-based articles could collect 1100 articles. A screening procedure is employed in the third stage to select and assess the applicability of retrieved research articles. Initially, the list is reduced to 875 articles by removing papers that failed to meet the study questions, are of poor scientific quality, have duplicate records, are written in languages other than English, or are not peer-reviewed. Additionally, based on title, keywords, abstract, and the deletion of articles from conference proceedings, papers in the press, periodicals, magazines, and book chapters, 390 papers were initially identified as relevant.

As a result, stage four of synthesis and analysis, after carefully analyzing results and conclusions using titles and abstracts. Reaching out to the 130 most notable papers involves an iterative process of thorough cross-referencing to ensure all relevant studies are included in the research, referring to highly cited articles, taking only empirical studies into consideration, full-text reading, and narrowly focusing on responding to research questions.

Furthermore, 104 research articles are accepted in stage five of reporting and putting results into practice to fully comprehend the state of the literature, which mostly takes into account empirical investigations. **Figure 2.8** represents the SLR process adopted in the current research. The literature review results helped the researcher identify important constructs and build a solid theoretical framework for this investigation. Therefore in **(Appendix 1),** the finalization of the constructs as an outcome of SLR is elaborated. In the next section, the researcher elaborates on the theoretical foundations of the study, the current status of I4.0, research themes, the constructs, and the development of models and hypotheses.

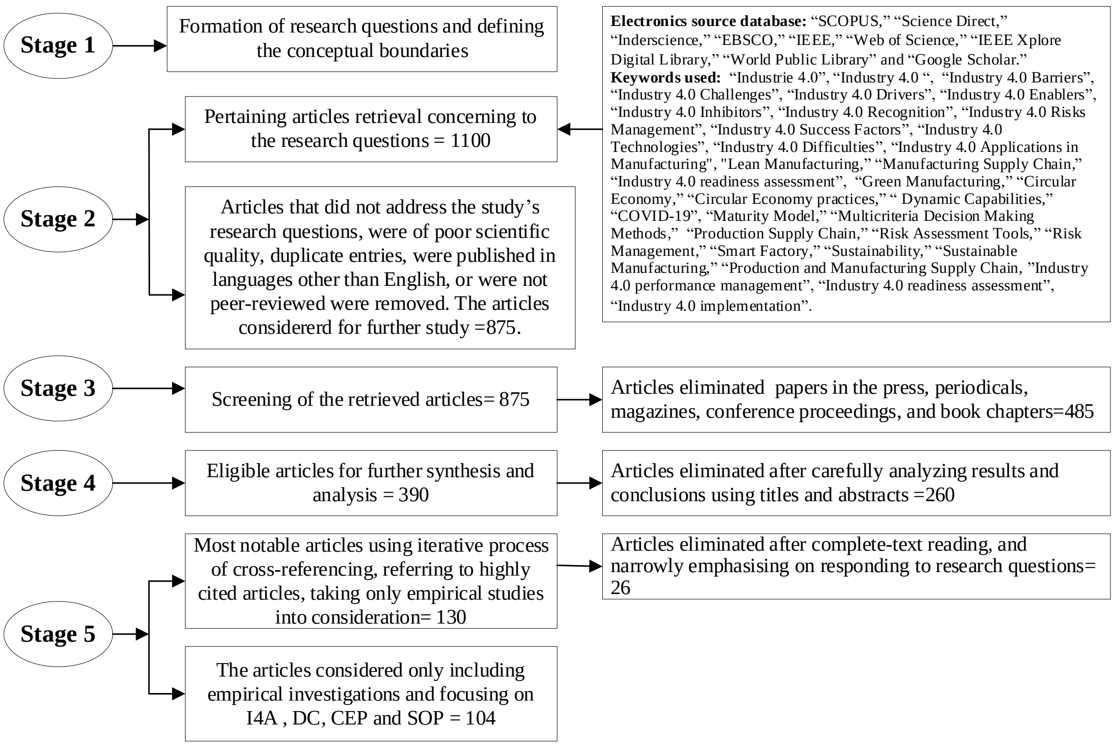

Figure 2.8: Systematic Literature Review Process Adopted in the Study

2.3 Current Status of Knowledge in Industry 4.0 and Research Themes

The literature review is grouped thematically to provide further context for the timeline of I4A in the manufacturing industry, focusing on India and from a broader viewpoint. Firstly, the emergence of technology and other areas like cyber security, data management, and workforce management-related articles are referred to examine the existing knowledge scope and viability regarding the current perception. Secondly, the government and regulatory body roles are examined in creating a conducive environment for I4A in the country. And thirdly, the barriers, drivers, enablers, and critical LR for constructs considered for the current study (I4A, DC, CEP, and SOP) are broadly studied in correlation with developing sustainable organizations.

2.3.1 Understanding the Fourth Industrial Revolution

Compared to all previous revolutions, the fourth industrial revolution is distinct and remarkable due to its pace and creative strategy (Caudill, 2020). Emerging technologies undoubtedly are the base of their tremendous potential. The first industrial revolution, guided by steam power-based mechanization, started in the 1760s (Monohan, 2017). The second industrial revolution focused on mass production using synchronized automation started in the latter part of the 19th century. The third industrial revolution, which started in the 1950s, introduced computers to manufacturing and production, leading to sophisticated, customized production that began in the 1950s. In 2011, the foundation for the Fourth Industrial Revolution was laid (Gartner, 2018). Over the years, the development of massive infrastructure and technology usage innovation proved key to the quick propagation of the 4th Industrial revolution. Developed countries experience forced the world to take note of positive changes in the economy and improved lifestyle of the people, that adoption of 4th Industrial revolution practices is in the interest of organization's sustainable growth (Bittner, 2019). One of the main advantages of this significant advancement is the vast and endless options that the internet of things offers. The fourth industrial revolution is envisioned as the coming of a digital deluge that will alter how businesses function in the future (Celaschi, 2017). This industry enabler is expected to provide a variety of small to big solutions, leading to the company's virtualization, more control over operations, and optimum utilization of resources (Nsakanda, 2021).

With the high pace of technological progressions in all business functionalities, they will find themselves confronted with a high demand for a workforce up to date with the most advanced skills (Guban and Kovacs, 2017). Research has found that the demand will not be limited to the industrial world but will also engulf personal lives (Afonso et al., 2016). This is further emphasized by (Mansori and Vuong, 2021), who also substantiated in their study that extreme dependence on technology will compel organizations to formulate sophisticated and sustainable strategies to open the doors to new geographical locations. The rapid acceptance of the technology will demand technocrats with new skills. If not dealt with in time, this mismatch may lead to a skills mismatch (Kuruczleki, É. Pelle, A. Laczi, R. & Fekete, 2016; Ossiannilsson, 2018). I4.0 is described as the most intelligent integration of innovative technologies (Wilson et al., 2021). Creating research-based solutions has become the most sought-after skill globally (Schiølin, 2020). Because the premise and context have changed, new solutions are needed for both new and old problems (Schiølin, 2020; Schwab, 2017). I4.0 practices have extreme potential to revamp organizational growth (Allan et al., 2017).

Organizations need to investigate leadership and employee uplifting in terms of their skills, knowledge, and understanding of I4.0 practices. Innovations in processes and advanced technology adoption should not be limited to a few employees but spread across everyone's profile. Continuous education and training could be another tool for ongoing upskilling (Albert, 2017). The leaders should share considerable responsibility because their role is key to restructuring the organization's performance (Fouda, 2020). In the world of digitalization, the ability of organizations to be agile, flexible, innovative, and collaborative would be the deciding factor for sustainability (Salter, 2017). The biggest challenge is enhancing performance without buckling down to external and internal pressures by engaging the right talent to transform the work environment (Ruel et al., 2021). Hence, the need for digital leaders who lead the organization by acting upon out-of-the-box ideas in the most dynamic environment is considered a primary need (Mayer and Oosthuizen, 2019). I4.0 leaders should also hold the ability to understand the needs of millennials in the employees and steer their potential to achieve competitive and innovative culture (Mayer, 2020). Introducing the most competitive smartphones as a medium to use digital technology is one of the strategies matching the millennial's aspirations. As every phenomenon has side effects, this disruption has also resulted in a few uninvited issues like skills mismatch, digitalization leading to division, and huge capital deficiency, thus the deleterious impact on numerous industries (Van Schalkwyk, 2020). Industries like manufacturing, banking, construction, and telecommunications are the worst affected (Bittner, 2019), with high-level retrenchment reported recently (Antony et al., 2020).

Emerging technologies are far more competitive and sustainable, no doubt, but it also brings a lot of burden on companies to adapt at a rapid pace. The emergence of I4.0 after the third industrial revolution signifies intelligent automation, data-based decision-making, virtualization of the physical world, and the high importance of data management (Webster, 2020).

2.3.2 Indian Government's Efforts to Propagate Industry 4.0 Vision in India

This section of the literature review addresses the status of Industry 4.0 adoption and awareness amongst different sectors and businesses in India. This exploration is important as to quantify the research gap and devise an appropriate action plan. One of the main objectives of this research is to help Indian industries to engage and take their share in the global technology led growth. Hence the research question being addressed here is 'Are Indian manufacturing industries aware of the I4.0 vision'?

Every democratic government must create a progressive environment and motivate businesses to achieve excellence. This study takes stock of international trends and government efforts to align local practices (Donald, 1999; Farole, 2019) to enable local companies to compete internationally. India, one of the countries with the fastest economic growth, is actively pursuing I4A in this context after discovering its impact on company operations. Initiatives taken by India have sparked a desire and a passion for incorporating new technologies into all facets of corporate functions. These initiatives, such as the (National Skill Development Mission, 2015) and the (National Education Policy, 2020), will fundamentally alter the educational system to make it more skill-based rather than information. One of ten global leaders, India, has revolutionized its manufacturing infrastructure by implementing cutting-edge digital technologies, according to the United Nations Industrial Development Organization (UNIDO), which has applauded its meticulous efforts (UNIDO, 2020). Only a handful of the several initiatives that have been developed to fulfill the objectives of national digitalization include SAMARTH Udyog Bharat 4.0 (SAMARTH Udyog Bharat, 2021), Atmanirbhar Bharat, eNAM, BharatNet, Make in India, and other government programs. The fundamental objective still encourages small firms to operate domestically while thinking worldwide. The Indian government is working hard to encourage the deployment of cutting-edge technology that will eventually help businesses produce goods and offer services globally, as per SAMARTH Udyog Bharat 4.0. India's strong export sector industrial development rate and the foundation of the "Engineering Export Promotion Council," engineering exports, which account for 25% of all product exports from the nation, are the largest source of foreign exchange for the country (EEPC, 2020). It exemplifies the Indian government's steadfast political dedication to raising I4.0 standards. The government, legislators, and business associations have all demonstrated a commitment to working together to advance I4A, creating jobs, increasing productivity, and the competitiveness of Indian manufacturing companies. Thus, by consistently deploying cutting-edge technology and making the most of these fortunate circumstances, the Indian manufacturing sector has consistently significantly contributed to the country's GDP (Khanzode et al., 2021). Thus, the I4A, which is also a major priority of the "Make in India" program, is now attainable because of India's march toward digitization (Kamble et al., 2018b). Another crucial marker of India's increasing digitization is a fast peek at its information and communication technology (ICT) architecture and user base. The most significant indicator of development is the dramatic increase in internet users in 2019 (23%) and reach in 2020 (48%), which aspires to connect 78% of India's whole population (Digital, 2022).

However, most Indian enterprises believe adopting the I4.0 agenda may not be practical without set norms and guidelines. Despite the apparent gap, few large-scale visionary firms have fully or partially embraced intelligent manufacturing processes because they fear adverse implications. Specific industries, such as the automobile, medicines, information technology, etc., are seeing considerable growth thanks to a few early adopters who are driving change (Khanzode et al., 2021). Most businesses have not yet started the I4A, except a few significant corporations, the government, and industry associations. Despite commercial successes, benefits, and the government's strong ambition, the I4.0 vision is not broadly implemented in a real scenario. The inadequate response from the industries has been attributed to a number of major challenges, including the need for capital investments, a lack of clarity in the economic feasibility of I4.0 applications, the absence of clear investment plans, a lack of proper skills, inadequate assistance from workers unions, a lack of digital leadership, and confusion in the digital vision (Sony and Aithal, 2020a).

Additionally, inadequate data protection, weak IT infrastructure, and limited internet access (Türkeş et al., 2019) are serious issues that could devastate if not appropriately addressed during I4.0 implementation (Khanzode et al., 2021). Also, Indian companies have been forced to lay off large manpower recently due to excessive automation and a lack of knowledge related to advanced skills. Therefore, organizations must be cautious and conscious of the technology adoption and the implied social risks. Neglecting the risks could be dangerous for the smooth adoption of the I4.0 vision

(Ofori and Sarpong, 2020). The I4A first mover's experiences, though, are quite inspiring. Therefore, there is a high possibility that the I4A will act as a game changer for Indian manufacturing companies.

2.3.3 The Public Sector's Impact on the Fourth Industrial Revolution

Governments mostly own public sector businesses aiming to create jobs, deliver high-quality healthcare, and foster the economy (Avis, 2018). Thus, the primary priorities for every government are to create long-term employment opportunities and to ensure public safety (Dean and Spoehr, 2018). This keeps the government under pressure as it directly threatens the economy (Mahomed and Smith, 2019). The matter is worst in developing countries, as the ongoing retrenchment adversely impacts the unemployment ratio due to I4A (Gavrilova and Gurvitsh-Suits, 2020).

Nevertheless, governments should also pay attention to the manufacturing sector, health care, transport, tourism, information technology, water services, education, and telecommunications sectors to encourage the adoption of innovative solutions (Houngbo et al., 2017). Other industries frequently view public sector initiatives as tried-and-true technological innovations, and as a result, they are incorporated into the creation of successful strategies for a sustainable economy. Because of this, the influence of this study has been examined in both the public and private sectors.

2.3.4 The Fourth Industrial Revolution from a Global Perspective

(The World Economic Forum, 2020)'s report urges developed and developing nations to identify innovative ways and means to maximize returns on I4.0 investments. Artificial intelligence is widely used to create smart products and services in developed countries. Considering how rapidly AI is developing, it is only a matter of time before industries begin to adopt digital services (Mansori and Vuong, 2021). This will further push governments to build new business models (Schiolin, 2020), which will be more aligned with market dynamics and advancements in technological adoption (Allen et al., 2022). Robotics, cyber security, AR and VR technologies, and AI will play a big role in revamping manufacturing, e-commerce, and telecommunications industries due to the fourth industrial revolution (Agovino, 2021). Contrary to it, according to Malthouse et al.(2019), laggards will not be in a position to take advantage of the artificial intelligence-enabled fourth industrial revolution due to economic and sociological factors (Gretzel and Kozinets, 2021). In the meantime, the United Nations has urged everyone to embrace digitalization and eliminate antiquated, inefficient methods so they can participate in future global trade (Kumar et al., 2021).

The Chinese government is keen to project itself as a world leader at the international level by increasing its capacity to create artificial intelligence-based business solutions (Liengpunsakul, 2021). Oxford Insights researched 193 nations to evaluate how well-prepared governments are to integrate AI into businesses and government operations. For a better understanding of technological advancement, the whole world could be divided into seven groups: Africa, Australia, Asia-Pacific, Eastern Europe, New Zealand, North America, Latin America and the Caribbean, and Western Europe, based on geographic location (Chung and Chung, 2021). The survey findings show that Singapore, the UK, Germany, the USA, Finland, China, and Japan, are at the top of the list, meaning they are very well prepared to include AI in business functionalities. India does not hold a place amongst the top few, but serious efforts are very visible to imbibe AI in industrial operations and business functions. A sluggish and lethargic adoption approach by few of the sectors, like textile and agriculture in the country is still a big challenge (Jacobs and Pretorius, 2020). Emerging technology implementation has failed in many developing countries because of a lack of interest, awareness, leadership, and political willpower. Instead of being reactive, companies should become proactive (Aghoghovwia et al., 2021). Government initiative through transforming and formulating relevant legislation and strategies is also important (Mayer and Oosthuizen, 2019). Robust infrastructure is another vital necessity for inclusive development. By the year 2025, the world is expected to process 163 trillion gigabytes of data, which will need highly reliable and credible data processing capabilities (Agovino, 2021). This capacity also reflects the ability to mitigate potential cybersecurity threats (Jacobs and Pretorius, 2020). Without this capacity, most developing nations may remain onlookers rather than becoming part of the system.

2.3.5 Industry 4.0 Emerging Technologies

Through cutting-edge software and internet networks driven by I4.0 developing technologies, I4.0 intends to connect physical items (such as different gadgets, equipment, sensors, actuators, and smart machines) with the virtual environment (Bajic et al., 2020). However, this would only be achievable if all company activities along the value chain were to seamlessly converge, automate, and digitalize (Bhatia and Kumar, 2020). Internet of things (IoT), Cyber-Physical Systems (CPS), Industrial Internet of Things (IIoT), Cloud Computing, Fog and Edge Computing, Augmented and Virtual Reality (AR/VR), Additive Manufacturing (AM), Robotics, Cobotics, Cyber Security, Big Data Analytics (BDA), Semantic Web Technology, Simulations, Product Life Cycle Management (PLM), Embedded Systems, and Network Manufacturing, Machine Learning (ML), applications, Cyber Security, Nanotechnology, Composite Materials, and Biotechnologies are a few of the names of emerging I4.0 technologies. Through forecasting, maintenance, problem diagnosis, and end-to-end control of operations in the intelligent factory, these technologies support autonomous and intelligent decision-making as well as the integration of production processes (Türkeş et al., 2019).

2.3.6 Manufacturing Industry Adoption of Industry 4.0

Manufacturing processes have seen significant change as a result of I4.0 technologies, including RFID, CPS, intelligent sensors, IoT, and AI. The fastest way to complete the production cycle and eliminate waste has been through (Müller et al., 2018b) merging the real and virtual worlds (Stentoft and Rajkumar, 2020). According to Müller et al. (2018a), authentic control over the production process, machine-to-machine interaction, and database administration have been made possible by this integration. A self-organizing, independent, and instantaneous decision-making system for the work floor was subsequently created as a result of this. The advancement of sustainability and interconnection, the creation of scalable enterprise through cutting-edge utilities, the improvement of product quality, and the efficient engagement of stakeholders are all great potential outcomes of this intelligent manufacturing. The analysis of massive amounts of information is another component of smart manufacturing. Colossal volumes of data created by machines in real-time are examined to enhance operations and processes, decrease costs related to errors and defects, and present opportunities for resource optimization, waste reduction, and problem-prevention (Awan et al., 2021).It has a great chance to offer details on upkeep methods, manufacturing processes, and consumer dynamics. This led to the understanding of client buying patterns, creative cost-cutting strategies, and techniques to assist manufacturing organizations in making more targeted judgments to satisfy unique consumer needs.

2.3.7 Smart Supply Chain in Industry 4.0 Adoption

On a worldwide scale, the storage and distribution of products and services continue to be major issues. Food valued at USD 2.6 trillion is wasted every year, which might have fed almost 8 million people in need. The most troubling feature of these losses is that 14% of them were attributable to inefficient SCM. Companies are relying on intelligent supply chain principles to find solutions to the crisis' growing severity. The market has shown that the use of new technologies has enhanced SCM performance across a wide range of sectors. A successful and creative SCM raises customer satisfaction by balancing supply and demand (Chandrasekaran, N. and Raghuram, 2014). In this changing environment, customers are becoming more demanding, so organizations must adopt a distinctive approach to value development and delivery (Handayati et al., 2015). It has been found that a thoroughly thought-out collaborative effort by building a partnership with producers, dealers, and manufacturers is a surefire way to long-term digitization (Fu et al., 2017). I4.0 intelligent technologies, such as virtual reality, CPS, IIoT, CC, and data analytics, have significantly impacted all business sectors since their development in 2011 (G. Yadav et al., 2020). The product's quality, environmental friendliness, and manufacturing process have also improved significantly (Tortorella and Fettermann, 2018). However, technology has also made it possible for companies to increase visibility, traceability, and adaptability at every phase of the value chain while maximizing their impact on the world (Hofmann and Rüsch, 2017). As a result, judgments are based on current information, giving those making them a thorough understanding of the problem (Casado-Vara et al., 2018) and improving the viability and traceability of decisions (Banerjee, 2019).

2.3.8 Industry 4.0 in Manufacturing and Production Supply Chain

The SC and logistics industry is currently being impacted by the disruptive advances brought forth by I4.0, as evidenced by the operations' increased flexibility and speed. (Long et al., 2019). Thus, implementing a new digital business plan, considering the demand's variety, volume, speed, and veracity, has unexpectedly risen to the top of the list of priorities on the new mandate (Xu et al., 2018). This strategy has certain benefits, but only if socioeconomic, legal, ethical, and technological barriers can be successfully identified and mitigated without harming corporate expansion (Long et al., 2019). Regrettably, this sector is highly susceptible to numerous regional and international risks (Lezoche et al., 2020). Adopting the appropriate technology and approach, alongside adjusting the current product and process and addressing environmental concerns, is one way to manage the uncertainties and expedite the transition (V. S. Yadav et al., 2020).

2.3.9 Lean and Green Manufacturing and Industry 4.0

Lean manufacturing focuses primarily on systematically removing waste from corporate activities (Bhattacharya et al., 2019). The earth's climate has experienced severe setbacks over the past few decades due to the unrestrained use of fossil fuels and the industries' careless behavior. As a result, the idea of green manufacturing gained traction and was adopted by operation management. The thorough analysis shows numerous parallels between organizational leadership, change management, and efficient resource management. However, organizations might have to make a trade-off because of the various generic focuses when implementing these concepts. Because lean manufacturing concepts do not consider environmental concerns, green manufacturing has become more significant (Siegel et al., 2019). Industries have more recently embraced the idea of "green manufacturing" to reduce manufacturing activities' harm. In a word, the Lean-Green idea focuses on minimizing the negative effects on the environment by lowering energy use, waste production, and emissions.
Emerging technologies like AI, Robotics, CPS, IoT, Radio Frequency Identification (RFID), smart sensors, and others have substantially impacted the end-to-end processes in the industrial sector. This is demonstrated by the high levels of agility, quickness, and efficient waste management that businesses have obtained due to the flawless integration of their physical and virtual environments (Stentoft and Rajkumar, 2020). The total product life cycle, data management system, machine-to-machine, and machine-to-human communications have all been significantly influenced by this merger. As a result, smart manufacturing—a real-time, data-based decision-making system that is extremely resilient, agile, self-organizing, and self-reliant—has emerged on the shop floor (Müller et al., 2018a). Further, smart manufacturing has the potential to enhance quality significantly, agility, productivity, and interconnection, leading to sustainability, the creation of value opportunities, and stakeholder engagement. BDA is yet another crucial element of smart manufacturing to improve the precision and accuracy of processes and operations (Wang et al., 2016). In real-time, BDA

successfully deals with the vast data's volume, variety, velocity, and veracity. As a result, chances are created to decrease mistakes, defects, costs, waste, and ideal time, as well as to maximize resources and improve system predictability, which increases return on investment (Awan et al., 2021).

2.3.10 Opportunities of the Industry 4.0

The fourth industrial revolution has transformed the manufacturer's approach toward business, and so does the consumer towards demanding the products and services. While many others are still undecided, some consider I4.0 an opportunity to achieve sustainability in businesses (Mpungose, 2021). The worldwide industrial sector has undergone a tremendous digital revolution as a result of I4.0. The innovations are intelligently fueled by the strong internet network, linked devices, and other auxiliary equipment (Ghobakhloo, 2018). I4.0's emphasis on end-to-end encrypting, sharing of information, data openness, and interoperability of physical and virtual systems improves the entire manufacturing process (Salam, 2019), raising manufacturing output and effectiveness (Büchi et al., 2020). It allows for the mass customization, scalability, agility, and flexibility of the manufacturing processes, which improves the company's ability to react swiftly to customer requests. Additionally, these technologies help modern industrial sectors to be more profitable by supporting improved quality, lowering costs, and reducing waste (Dutta et al., 2021). Therefore, the I4A presents the opportunity to transform the current manufacturing environment into the smart factory of the future, which will be highly efficient, digitally networked, and resourceful in addressing operational problems in real time (Moeuf et al., 2018).

According to (Philbeck and Davis, 2018), the fourth industrial revolution allows enterprises and society to produce intelligent products and services for a brighter future using advanced technology. With the emergence of advanced technologies and extensive use of smart gadgets, people's travel, experience, plan and think about responsible consumption have also increased (Chiles et al., 2021). This impact is also seen in the labor approach toward the work. Intelligent automation derived from artificial intelligence and robotics is laying the foundation for the future of labor (Kim et al., 2021). I4.0 have challenged industries, mainly in developing nations, to adopt research, innovation, and data management while developing future strategies necessary for running the business effectively and generating additional employment.

Companies should identify and promote the skill in demand and systematically phase out those on the verge of getting obsolete. On this count, AI, cyber security, data management, and robotics are identified as skills in high demand (Llale et al., 2020). Rapid propagation of AI in industries is considered an excellent opportunity to imbibe intelligence in the system.

Two main aspects of these smart machines, software, and hardware, are expected to generate hybrid employment opportunities, which will need a workforce with advanced skills (Kudyba, 2020). Hence, companies should not be scared of including AI (De Bruyn et al., 2020) but devise a practical approach to strengthen cyber security, data transfer, interface creation, and virtualization of the existing system (Kudyba, 2020). Organizations must be thoughtful while deploying and upskilling the current workforce as a first option (Liu et al., 2021). Older generation employees may not pose high productivity and learnability as the younger generation may, but the balance has to be stricken (Cardinali et al., 2021). Every organization should continuously upgrade the list of future skill sets by identifying and nurturing them before it is too late (Liu et al., 2021). Governments should promote a collaborative approach to sharing technological breakthroughs (Allen et al., 2022).

2.3.11 Barriers to I4.0 Implementation

Every element of the company has been impacted by the growth of I4.0, making it more stringent. Beyond a doubt, first-mover businesses are privileged and currently dominate their respective industries. Even when I4.0 is presently a reality, difficulties must be taken into account as it is being developed (Rezqianita and Ardi, 2020). One of the fundamental requirements of the I4A is the ability to communicate between machines and humans, only utilizing artificially intelligent solutions. According to systematic investigation, AI will eliminate and generate new jobs (Lee et al., 2020). Specifically in areas where AI capabilities will not match minuscule human capabilities (Lee et al., 2020; Ozkazanc-Pan, 2021). Industries will be compelled to adopt AI solutions; those who do not risk losing ground to their competitors. Machine learning, another name for AI, is a set of tools that precisely receive inputs and process them into the output in a manner that is at least as good as what a human would have done (Krafft et al., 2020). This makes machines undeniably intelligent.

Rezqianita and Ardi (2020) conclude that when implementing I4.0, policymakers must give equal consideration to technological, organizational, governmental, and budgetary challenges. CPS, IoT devices, data storage, machine-to-machine communication, cloud computing, etc., all require high-speed, uninterrupted broadband internet access when functioning in real-time over integrated internet networks, mandating an effective internet network (Akdil et al., 2018). There are issues with an elevated, low-latency available bandwidth of the internet and cybersecurity due to this real-time sharing of enormous volumes of sensitive firm data and information exchange across the whole supply chain network (Caiado et al., 2022). Another difficulty that technocrats and managers encounter as the digital corporate operations are the lack of standards and benchmarks. To enable smooth data transfer between various stakeholder groups, including government regulators, manufacturing systems, machines, logistics providers, and consumers across the entire value chain, a set of guidelines built on dynamic optimization models is required (De Vries and Van Wassenhove, 2020).

2.3.12 Risks in Industry 4.0 adoption

The I4A intends to promote corporate sustainability by skillfully managing technology, productivity, and automation in every business process. The business process becomes increasingly difficult as personalization increases. Thus, it seems inevitable that all stages of the product life cycle will be heavily digitalized, leading to enduring uncertainty. According to Leonhardt and Wiedemann, (2015) , the research investigated risk-related uncertainty, and its sources are essential. Operational hazards are incidents that could happen when a corporation is conducting internal and external operations. The production environment, human capital, machinery, and equipment environment are directly tied to these incidents, as are other I4.0 components (Lin et al., 2019). According to Birkel et al. (2019), the risk faced by I4.0 technology, the legal/political climate, the environment, and the economy all have a greater impact on the risk structure, which requires evaluation for I4A response. According to Calabrese et al. (2020), the ineffective I4.0 competent legal framework and poor I4.0 standards have exacerbated the legal risks, making I4.0 implementation challenging for industrial businesses. I4.0-related technology may monitor and manage aspects that lead to pollution, lowering environmental concerns and eliminating overt human involvement. Therefore, industrial enterprise researchers and practitioners must evaluate the significance of these expected risks to utilize the I4.0 advantages fullest (Moktadir et al., 2018). This necessitates increased cooperation in studies analyzing and evaluating environmental risks (Gobbo et al., 2018).

2.3.13 Adoption of Industry 4.0 and COVID-19

Regardless of geography, economic development, technology innovation, corporate size, or ownership, the pandemic has impacted every industry worldwide (Nicola et al., 2020). Small, medium-sized, small, and micro firms are the most negatively impacted since they outsource most of their tasks outside of their core competencies because they lack limited resources, automation, and knowledge (Nicola et al., 2020). Many businesses are still at critical junctures due to a lack of clear direction even though the I4.0 ideology was established a decade earlier in 2011; as a result, they are unable to keep up with the rapid speed of digitalization and customer expectations (Narayanamurthy and Tortorella, 2021). During this pandemic and the lockdown, two schools of thinking emerged. One group is adamant that the epidemic has destroyed all development plans and established enterprises' position in the market, while the other group believes the pandemic has created a wealth of opportunities to create sustainable company operations (Cohen, 2020; Narayanamurthy and Tortorella, 2021). The lesson is clear: in order to minimize any external pressures, the need for a strong, self-sustaining ecosystem that is adaptable, resilient, and agile (Ivanov et al., 2021). The pandemic has massively accelerated digital transformation in industries and society, which cannot be disputed.

2.4 Literature Review for the Constructs Finalization for the Current Study

Further, the literature review has been carried out to find out the most relevant and impactful constructs, which are significantly impacting the overall progression of I4.0 amongst the Indian business sectors. Although the business sector's capacity and capability differs, but strategically all are aligned on the growth aspirations and challenges of technology adoption. Hence the research question, 'What are the crucial constructs impacting the I4.0 progression in the manufacturing industries of India?' is addressed here.

2.4.1 Industry 4.0 Adoption Drivers

I4.0 refers to a group of several technological solutions that combine to improve organizational performance. Such technologies help executives with equipment upkeep, production scheduling, planning capacity utilization, and energy management (Szalavetz, 2019). IoT devices use sensors, actuators, and RFIDs to create data that can be analyzed for sound decisions and long-term business success (Jain et al., 2017). Artificial intelligence (AI) and robotics are required to produce elevated-quality products with little human involvement (Corò et al., 2020). As a cost-effective alternative for organizations, cloud computing offers a virtual data backup and recovery platform that can be managed using the internet network. It facilitates secure information transmission (Marino et al., 2021; Pierdicca et al., 2017). Employee hands-on training, essential components of maintenance tasks, tracking stocked devices and replacement parts storage facilities, logistics, remote machine operation, and coordination, safety practices, quality standards, product designing phase prototyping, etc., are all practical uses for AR/VR technologies. I4.0 technologies should therefore be viewed as essential I4.0 development and SOP accelerators. Organizational tactics have a significant impact on how I4.0 is implemented. Businesses must act swiftly to find solutions to the issues relating to monitoring, regulating, and maintaining an organization's total digitalization because it is the most significant transition. To encourage cooperation and complete endorsement of the business and manufacturing process improvements, an estimated and suitable deployment of agents of change, instructors, and counselors is required (Narula et al., 2020). The organization needs to develop managerial and management strategies and policies to support I4A in order to address this successfully. As a result, employees will gain skills and embrace a digital culture, senior management will become involved, and R&D activities will be encouraged (Sony and Naik, 2020).

By exploiting the productivity, quality, and entire production system offered by I4.0 technologies, firms are able to compete with their competitors (Horváth and Szabó, 2019). In underdeveloped nations compared to industrialized nations like the US and Germany, the digitization revolution is rather delayed. While developing countries are more focused on the need for financial resources and return on investment, developed countries place more emphasis on branding. I4A has received negative economic perceptions, particularly in less developed nations (Tay et al., 2021).

By learning to restructure, rearrange, and take planned, proactive steps to counter flaws and start offering remedies based on earlier experiences, smart goods can support manufacturing processes (Stock et al., 2018). Because the supply chain is transparent, adopting smart operations can boost the productivity of the production process by operating and reacting in real time. Lowering the cost of customization will ultimately increase product quality and flexibility and satiate consumer demand for products (Enyoghasi and Badurdeen, 2021). As a result, smart products and processes are believed to have a big impact on the I4A. A balanced approach to the management of human resources should be employed to enhance an organization's performance and provide seamless integration to I4.0. The skills and information that employees bring to the table help a company succeed (Lin and Huang, 2020). As a result, a company should provide its staff with the drive and skills they require to reach the I4.0 criteria. Client needs may be satisfied with additional flexibility, adaptability, and reactivity as a result of digitalization (R. Kumar et al., 2020). A successful, intelligent, educated consumer is crucial for a sustainable manufacturing company. Consumers' confidence in the caliber and reliability of the company and its products will thus rise if they have access to process transparency and visibility throughout the product life cycle via an appropriate digital platform (Dutta et al., 2021). Businesses may acquire a competitive edge by adopting digital transition, paying attention to consumer desires and expectations, and introducing customer-oriented changes into strategic planning to fulfill their needs (Adolph et al., 2014). Partners like customers and employees are thus considered to be one of the pushing drivers behind I4.0.

I4.0 standards are external, uncontrollable factors that hinder the growth of I4.0 and the capacity of businesses to change (Yalabik and Fairchild, 2011). Hence to hasten the I4.0 revolution, frameworks, reference architectures, and IT infrastructure must be built according to established standards (Sung, 2018).

2.4.2 Industry 4.0 Adoption and Dynamic Capabilities

Any organization's structured and thoughtful approach to harnessing unique outcomes in products or services from available resources can be defined as the organization's dynamic capability. Dynamic capability refers to an organization's capacity to combine, enhance, and reorganize internal and external resources and competencies to respond quickly to shifting business situations (Teece et al., 1997, 1991). Certain change routines and analyses (such as product development following a defined trajectory) could, at times, provide the framework for dynamic capabilities (i.e., investment choices). But at their core, they frequently exhibit creative, managerial, and entrepreneurship activities (e.g., pioneering new markets). They show how fast and efficiently the business may reorient its special assets and competencies to seize opportunities and satisfy market needs. Strong dynamic skills enable a company to produce outstanding results. The researcher discovered literature in this context that reflects the potential of I4.0 technologies and dynamic capabilities to impact organizational sustainability together (Díaz-Chao et al., 2021). Thus, I4.0 practices boost an organization's dynamic capabilities (Bag et al., 2021a). The dynamic capabilities are represented by the degree of agility, resilience, flexibility, and speed of the functions (Warner and Wäger, 2019). Thus, the emphasized investigation of the interrelationship among the drivers of DC and then quantifying the impact of I4A supported by imbibing emerging technology in operations is important and needs the attention of researchers.

2.4.3 Circular Economy Practices

Despite the numerous benefits of adopting I4.0 and CEP, resources are still being lost annually, mostly because of poor management techniques, a lack of motivation, and the reluctant acceptance of technology by unskilled workers (Chauhan et al., 2021). One prevalent method for reducing waste and reaching Sustainable Development Goals is adopting CEPs. The CEP encourages the best use of resources by focusing on recycling, reuse, and recovery techniques (Luttenberger, 2020).

The degree of customization and business requirements also have a role in the net realization of the advantages (Pham and Verbano, 2022). The Supply chain, which concentrates on delivering reconditioned, reused, or refurbished items for recycling or return, is clearly affected by CEP (Pham and Verbano, 2022). The application of CEP involves cooperation between the client, the manufacturer, the regulator, and the suppliers. Once supported by technology, this integration will help to create effective and environmentally beneficial behaviors that will inevitably result in sustainable development (De Corato, 2020). The fact that CEP offers process visibility, consistency, feasibility, and traceability linkages that no other method can is another advantage. However, the organization may occasionally be burdened by expenditures related to societal, ecological, and economic difficulties (S. S. Kamble et al., 2020). India is one of the most significant contributors to the world economy thanks to its enormous industrial and production capacities. Additionally, this compels the country to embrace sustainability CEPs (Mangla et al., 2020).

According to Rajput and Singh (2019), The performance standards of the processes and operations of the enterprises that adopt I4.0 and CEP show steady improvement. The businesses have also embraced a cooperative strategy to share knowledge and implement programs, opening up opportunities for greater success and advantages (Nascimento et al., 2019).

2.4.4 Sustainable Organizational Performance

SOP refers to an organization’s ability to meet stakeholder needs while continuously improving managerial and investment strategies and policies to promote long-term financial success, social advancement, and environmental sustainability (Pantelica et al., 2016). Manufacturing companies are paying greater attention to creating SOP as a result of demand from the competitive market. To achieve sustainability, operational flexibility, cost, time, and quality analysis are all essential; concentrating only on economic issues is insufficient. In addition to all of this, businesses must be cognizant of their social and environmental obligations, which include satisfying the needs of picky clients, managing a flexible workplace environment, and reducing waste, energy use, recycling, and carbon emissions (Ben-Daya et al., 2017; Marimuthu et al., 2021). For this, it is essential to balance these sustainability indicators—economic, social, and environmental; I4.0 might make this possible (Galati and Bigliardi, 2019). The literature reveals that I4.0 technologies and the SOP have a good working relationship (S. Kamble et al., 2020). Despite this, empirical research on the effects of I4A on SOP while taking into account other I4.0 drivers is underutilized. This urges the researcher to consider the SOP as one of the most crucial constructs in the investigation.

Many academics working in a range of functional domains, particularly those focusing on I4A, have lately highlighted the theoretical foundation of SOP as a crucial construct (Haseeb et al., 2019; Müller et al., 2018b). If I4.0 is to be efficiently directed, it will analyze the effects of I4A in the framework of its drivers on long-term organizational performance while bringing CEP and DC into account. Two widely used strategic management theories—the Dynamic Capability View theory and the Contingency theory—serve as the foundation for this research (Bag et al., 2021a; Kloviene and Uosyte, 2019; Sony and Aithal, 2020b).

Organizations appear to be adopting I4.0 technology to satisfy sustainability criteria. Organizational strategies, financial investments, intelligent products and operations, stakeholders such as employees and customers, government policies, and I4.0 standards are seen as the key drivers of I4A along with the I4.0 technologies (Müller et al., 2018b; Rachinger et al., 2019; Schumacher et al., 2019). The research identified the key drivers influencing the adoption of I4.0 are leadership strategies, organizational culture, and I4.0 technology (Narula et al., 2020; Stentoft and Rajkumar, 2020). Hopkins (2021) contends that while expected financial results and investment requirements are uncertain, I4.0 technologies are likely to accelerate I4A. But it appears that I4A makes use of manufacturing businesses' SOP (S. Kamble et al., 2020). I4.0 drivers' effects on I4A have been the subject of sporadic research in the past, much of which has concentrated on I4.0 technology drivers (Corò et al., 2020), with little or no attention paid to other drivers. As a result, the lack of an empirical methodology for evaluating the impact of the key I4.0 drivers that have received the most attention individually on I4A is slowing down the implementation process. Also, in the literature, it is observed that very minimal attention is provided to the relationship between I4A, DC, CEP, and SOP, which the researcher found is the urgent need of current manufacturing businesses to achieve a sustainable competitive edge. This prompts the researcher to investigate how the most important determinants of I4A, DC, and CEP and how all collectively affect the SOP.

The status of the literature review undertaken till now reveled that large number of businesses are on crossroad, in the absence of robust yet simple model which may lay the foundation of systematic emerging technology adoption. Researcher has confirmed that the outcome of this research aptly meets the expectations by addressing the research question, 'What constitutes a feasible and viable I4A model?'

2.5 Underpinning Theories

2.5.1 Dynamic Capability View Theory

The dynamic capabilities view theory introduced by Teece et al. (1997) is the advanced version of the resource-based view theory (RBV) as introduced by Barney (1991). Researchers frequently apply DCV to operational and strategic management decision-making issues. RBV describes the approach a firm should adopt in certain conditions to be different from the competitors based on the resources and capability it holds (Barney, 1991). This static nature is the limitation as it failed to explain the approach a company should adopt to remain competitive in a dynamic and continuously changing market environment (Priem and Butler, 2001). With the evolution of technology, the market dynamics are changing on a daily basis; hence the RBV could not sustain the firm's demand to be agile and resilient. At the same time, the dynamic capabilities theory has the scope to help senior managers of businesses to develop plans for adapting to severe change while maintaining the capacity and competitive edge in the market. According to the dynamic capabilities theory, a firm's competitive advantage is explained by the ability to deploy unique, rare resources in a rapidly evolving market environment without delay. A real-world scenario would have a very dynamic corporate environment. By time, place, and business importance, every circumstance is distinct. It follows that dealing with the possibility calls for particular skills. Managers need to know how to apply their special competencies to the issue at hand. In order to remain competitive, minimize risk, and gain an advantage over rivals, DCV plays a significant role. A company's ability to rapidly adapt to changing circumstances by restructuring, integrating, and expanding its internal and external capacities is referred to as DCV. Another approach to further characterise dynamic capabilities is its capacity to foresee and seize opportunities to maintain a competitive position by updating, integrating, safeguarding, and, as necessary, redesigning the company's assets and resources (Teece, 2007). As an alternative, dynamic capabilities are an organization's capacity to allocate/use corporate resources per the demands of a changing environment while considering its dynamic business processes for value creation.

Therefore, organizations need solid strategic planning to reduce or offset the effects of any high-level unpredictability brought on by environmental change (Mofijur et al., 2021). This will help the company achieve its goals of strategically defeating rivals and gaining a larger market share. Companies can evaluate their current product, pricing, and demand forecasting methods and replace them with more sophisticated, data- and technology-based methods that can help them accomplish long-term business objectives. In order to achieve SOP as the intended outcome to compete in the market and demonstrate its unique identity, it is crucial to recognize and govern the organization's dynamic capabilities, particularly the I4.0 drivers for I4A, DC drivers, and CEP drivers whose performance has heavy impacts on SOP. Thus, DCV theory is crucial in addressing all of these issues. The DCV theory is the foundation of the proposed I4A model. The context is taken from previous research and adjusted as per the objectives and specifications of the current investigation. As the demands of the external environment changed, DCV's ability to continuously monitor and control capacities and guide and nurture transformation together revealed opportunities like never before. A strategy like DCV's is necessary for making strategic choices in a dynamic corporate setting; it is nimble, intelligent, and engaging. In this research, DCV theory explores the significance of important success criteria for I4A, DC, and CEP as well as their individual effects on these constructs. Thus, it is confirmed that the theory choice is appropriate for the problem undertaken for this study.

2.5.2 Contingency Theory

The ideal structure of an organization is determined by its operating environment, claims contingency theory (Betts, 2011). The firm's strategy for solving the particular problem differs due to the constantly shifting external circumstances, which also prevents them from adopting ready-made solutions from what appears to be a competitor organization. Because the environmental conditions will vary from situation to situation, this theory unequivocally demonstrates that there is no universal solution to similar or identical problems (Galbraith, 1973). As a result, in order to attain high levels of performance inside an organization, the structure and resources of the company must be in harmony with the contextual environmental elements (Tosi and Slocum, 1984).

Recognizing and creating valuable connections between environmental, managerial, and performance variables are what is meant by the term "contingency strategy" (Luthans and Stewart, 1977; Tosi and Slocum, 1984). The three main components of contingency theory are environmental factors, resource variables, and management variables. These three components interact to create secondary variables such as scenario variables, organizational variables, and performance criteria variables. As shown in **Figure 2.9 and Figure 2.10,** the contingency model of the organization and a derived model from contingency theory for the current research elaborate on the relationship of the constructs considered for the current research.

It is clear from the current literature on operations management that contingency theory was the most preferred theory throughout its early stages of development. The theory is widely accepted for two reasons, as can be seen in the case of the majority of theoretical models. First, as the theory suggests, it makes sense that there isn't always just one best course of action to take, and second, early studies yielded positive and seemingly converging results. Later, the theory is challenged by several issues, such as a lack of precision, deterministic presumptions, and the absence of a cultural effect. Therefore, the author established this theory as a theoretical foundation to explore the link between the investigated primary and secondary variables. The scope and avenues for the desired organizational performance enhancement can be investigated based on contingency theory by looking at relevant contextual factors such as manufacturing practices, I4A, CEPs, DCs, and environment management practices with their desired outcomes, i.e., organizational performance enhancement (Chauhan et al., 2021; Sousa and Voss, 2008). This made it easier to comprehend how different contingencies operate and may also be utilized to assess novel circumstances involving previously unrecognized confluences of contingency elements (Betts, 2011). According to the contingency theory-based approach, the impact of the I4A, DC, and CEP considering their environment on SOP measurement, are the key contingent factors in the I4A decision-making process. Researchers can choose from various variables, such as time and strategic choice, to suit the organization's demands and then hunt for common combinations of these variables in other scenarios (Miller, 1981). The well-known contingency theory and DCV theory, which have been the researcher's first options in situations like these, serve as the inspiration for this work. Through a theoretical lens, it has been determined that both theories are the most appropriate for investigating and evaluating the influence of I4A, DC, and CEP drivers on themselves in the first and second stages of evaluating their overall effect on SOP.

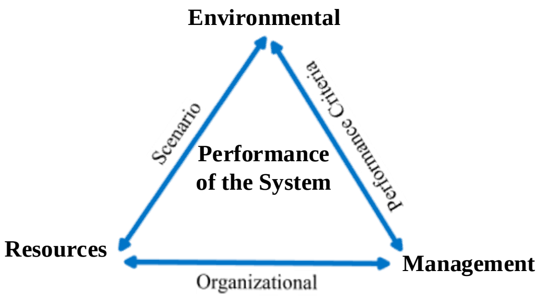

Figure 2.9: The Summary of the Variables and their Relationships in the Organization's Contingency Model **(Source: Luthans and Stewart 1977)**

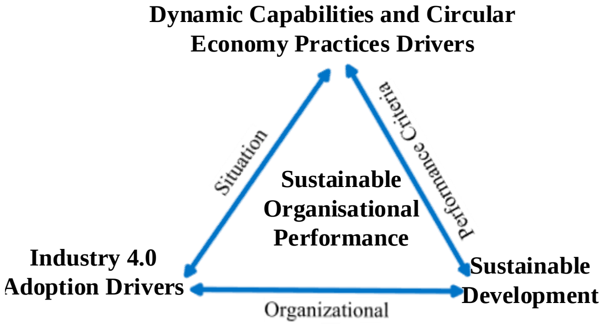

Figure 2.10: Derived Model from the Contingency Theory for the Current Research (Source: Author's own work)

2.6 Prior Research Studies Identified in Industry 4.0 Domain and Tools and Techniques used.

It takes the right tools and processes to evaluate and analyze business-related decision-making issues and overcome obstacles. In this context, the description of previous studies emphasizes research methods and instruments, and their value to the I4.0 domain elaborates in **Table 2.8**.

Table 2.8: Past Literature Contribution and Tools and Techniques used in Industry 4.0 Domain

SN	Contributions	Study Findings	Tools Used For Analysis	Literature Support
1	Addressed a glance at smart manufacturing and I4.0 practices and extracted the future research scope.	For infrastructure to support an I4.0 to be implemented, a fast broadband internet connection network is required.	LR	Thoben et al. (2017)
2	Risk assessment and prioritization in reverse logistics.	The role of effective and efficient inventory management is a must in reverse logistics. The risks associated are highlighted, along with clearly identifying customers' role in solving social issues and environmental protection.	AHP, FTOPSIS, and PROMETHEE	Senthil et al.(2018)
3	The influences on the criteria used for people selection in an I4.0 workplace have a proven causal relationship.	Critical factors identified are required while carrying out the tasks and responsibilities, problem-solving, concurrent thinking, and adaptability.	fuzzy DEMATEL	Kazancoglu and Ozkan-Ozen (2018)

SN	Contributions	Study Findings	Tools Used For Analysis	Literature Support
4	I4.0 implementation risks prioritization.	Risks associated with the manufacturing process are found to be the most crucial.	Interval type-2 FAHP and hesitant FTOPSIS	Colak et al.(2019)
5	The triple bottom line of sustainability is used to develop an I4.0 risks framework.	According to the study's conclusions, risks relating to the economy, society, law, politics, environment, technology, and information technology must first be addressed.	SLR and Interview	Birkel et al. (2019)
6	Developed a performance measurement model to assess the organization’s export.	An organization’s export performance may be measured by assessing, achieving strategic objectives, and generating a profit.	SWARA and ARAS with IVTFNs	Dahooie et al. (2020)
7	Assessment of sustainability metrics for the system of renewable energy.	Environmental sustainability criteria are determined to be the most crucial of the three.	SWARA and ARAS	Ghenai et al. (2020)
8	Framework development suggests adopting I4.0 and CE solutions to mitigate SSCM challenges.	According to the research, every firm needs to address its organizational, management, and economic SSCM concerns.	BWM and ELECTRE	Yadav et al. (2020)
9	Blockchain implementation toward risks assessment.	According to the survey, the most significant risks are security concerns, followed by energy prices and data theft as the most significant subfactors.	SVNSs, AHP, and DEMATEL	Abdel-Monem et al. (2020)
10	Established the critical role of KPIs in the deployment of I4.0.	The study identified crucial KPIs for I4A and its relationship with corporate social responsibility.	Literature review	Žižek et al. (2020)
11	This study aims to establish a viable model for business-to-customer straight shipment using a mixed-integer programming approach while considering supply risks and transportation concerns.	The study found that the cost of the process and organizational resilience, flexibility, and ability to invest in resources towards reducing the risk is far less than the revenue lost due to addressing supply chain risks while dealing with overwhelming unmet demand or subpar customer service.	Integer programming	Prakash et al. (2020)
12	Identifying and assessing risks associated with circular supply chains and formulating solutions.	The leadership role is found to be crucial in formulating organizational policies and mitigating circular supply chain risk.	PF-AHP, PF-VIKOR	Lahane and Kant (2021)
13	Big data analytics barriers evaluations.	The most important factors in Big Data analytics techniques include limited data storage capacity, weak organisational strategies, uncertainty over	Grey DEMATEL	Raut et al. (2021)

SN	Contributions	Study Findings	Tools Used For Analysis	Literature Support
		return on investments, and insufficient IT infrastructure.		
14	Assessment and identification of implementation drivers for intelligent manufacturing	It has been determined that interoperability is the key factor in intelligent manufacturing.	Grey TOPSIS and COPRAS-G	Malaga and Vinodh (2021)
15	It was determined through a bibliometric study that I4.0 plays a crucial part in catastrophe risk management..	The goal of this study is to reduce disaster risk reduction in the construction sector using the Sendai Framework. The significance of I4.0 technologies in disaster management was recognized. Six target region clusters were identified and mapped based on priority using the study's findings.	Bibliometric Analysis	Habibi Rad et al. (2021)
16	The study determined the function of blockchain, big data, artificial intelligence, cloud computing, and these technologies in I4.0 risk management.	The study looks at how I4.0 technologies affect risk management, focusing on market pressure, legal requirements, the level of digital transformation maturity, and the usefulness and resilience of the technologies.	Structural Equation modeling	Rodríguez-Espíndola et al. (2022)
17	I4.0 technologies are evaluated using established KPIs, and decision-makers are given recommendations on I4.0 implementation and performance assessment.	The study’s major objective was to offer the industries a ready-to-use solution. Used a case study methodology to demonstrate the value of the produced KPIs.	Literature review and case study	Braglia et al. (2022)
18	Created a sustainable approach for managing supply chain risks for Pakistani logistic firms.	The study found an organizational risk is the most significant, and environmental risk is the least significant.	Fuzzy-Based VIKOR–CRITIC	Ul Amin et al. (2022)
19	Identification of I4.0 implementation obstacles in the food supply chain.	The biggest obstacles include a lack of consumer awareness and acceptance, a sizable financial investment, subpar technology, and a lack of environmentally friendly innovation.	Rough-DEMATEL	A. Kumar et al. (2022)
20	The I4.0 challenges’ causality analysis	The hierarchy of trigger categories is arranged from top to bottom, with technological advancement and a lack of a regulatory framework on the top. The main obstacles noted are the difficulty in obtaining finance and aversion to change.	DEMATEL	Khanzode et al. (2021)

SN	Contributions	Study Findings	Tools Used For Analysis	Literature Support
21	Sustainable human resource management has difficulties as a result of I4.0 disruption.	The study identified continuous training facilities and job stability as major obstacles.	Fuzzy BWM	Agarwal et al. (2021)
22	Identification of I4.0 challenges	The Internet of Things (IoT) and cybersecurity were identified as the two most important challenges in this study.	DEMATEL-MMDE-ISM	Singh and Bhanot (2020)
23	Creation of a framework to solve SSCM problems	Management, economic and organizational obstacles are significant.	BWM-ELECTRE	Yadav et al. (2020)
24	I4.0 enablers identification and assessment.	The study established the support of top management crucial for any cultural change.	ISM MICMAC	Devi K et al. (2020)
25	Establishment of contextual relationships amongst I4.0's sustainable functions.	The innovativeness and effectiveness of the I4A business model have an impact on the sustainability of the economy.	ISM MICMAC	Ghobakhloo (2020)
26	Recognition of I4.0 enablers	The most effective enablers are financial assistance, less expensive internet, government services, ongoing education, and workforce development.	TISM and Fuzzy MICMAC.	Jain and Ajmera (2020)
27	I4.0 barrier grouping and ranking.	The primary barrier was an absence of transparency in the cost-benefit analysis, which was followed by a lack of comprehension of the advantages. Other significant challenges included the outdated machinery and equipment in the new layout, the lack of standards, a workforce lacking in the required skills, a slow IT infrastructure, and an inadequate data protection system.	PCA-Fuzzy AHP-K means	Kumar et al. (2020)
28	Proving a link between I4.0 barriers and their cause	The major challenges are a lack of money and a weak digital strategy. The paucity of I4.0 standards, a well-functioning system of governmental regulations, and regulatory requirements that have an impact on I4.0 implementation, however, pose the most challenges.	Grey DEMATEL	Raj et al. (2019)
29	Identifying and evaluating I4.0 enablers	The study discovered that the IoT platform, Big data, and IoT are the most important enablers.	PCA-ISM-DEMATEL	Rajput and Singh (2019a)

SN	Contributions	Study Findings	Tools Used For Analysis	Literature Support
30	Elucidated the causal link between I4.0 barriers	Lack of education, information, and awareness are important elements that trigger the other barriers, such as a lack of ICT adoption, a lack of tenacity, and a scarcity of skilled people.	Interview and ISM and MICMAC	Karadayi-Usta (2019)
31	Setting the I4.0 challenges' priorities	The biggest barrier to I4.0 deployment is a lack of technological infrastructure.	BWM	Moktadir et al. (2018)
32	Establish contextual relationships among the I4.0 barriers.	Critical obstacles included the company's legal standing and capacity to sign contracts without violating the framework.	ISM and Fuzzy MICMAC.	S. S. Kamble et al., (2018b)
33	I4.0 Barrier identification	Critical barriers identified are technological innovation.	Interviews, thematic analysis	Long et al. (2016)
34	To learn about difficulties and trends	Industry 4.0, environmental preservation, and safety were all cited in this report as major obstacles.	Soft system methodology (SSM), Interviews,	Liboni et al. (2018)
35	Development of contextual relation.	I4.0 relationship with CE	ISM	Rajput and Singh (2019b)
36	Identification, relationships, and setting of priorities between functions.	I4.0 and sustainability	ISM	Ghobakhloo (2020)
37	Challenge identification.	Prominent CE challenges	Case Study	Sehnem et al. (2020)
38	Challenge identification, inter-relation, and priority establishment.	CE and SC relationship	Delphi, ISM	Joshi et al. (2020)
39	Driver identification.	CE and SC relationship	Failure mode and effect analysis, Stepwise Weight Assessment Ratio Analysis,	Yazdani et al. (2019b)
40	Factor Identification.	SC and sustainability	Semi-structured interview and PCA	Joshi et al. (2020)
41	A model of fuzzy-based risk assessment for the I4.0 Transition Process.	This study assessed the following Risks • Management of the manufacturing process • Operations management using appropriate methods and tools • Making use of the right tools and manufacturing techniques and effective use of human resources	Interval Type-2 Fuzzy AHP, Hesitant Fuzzy TOPSIS, MCDM	Colak et al. (2019a)

SN	Contributions	Study Findings	Tools Used For Analysis	Literature Support
		• Conducive environment for Machine-Machine communication.		
42	An I4.0 organizational adoption assessment model	Utilized the self-assessment analytical model to evaluate readiness/maturity to implement I4.0.	AHP TOPSIS	Demircan Keskin et al. (2019)
43	Investigating the key success factors of SSC for I4.0	This study discovered that a supportive IoT ecosystem was key to I4.0's success.	DEMATEL	Bhagawati et al. (2019)
44	Building a Risk Framework for I4A in a sustainable environment for established manufacturers.	This study developed a framework to deal with I4A risks that may occur during or after adoption.	Literature review and interview	Birkel et al. (2019)
45	Pervasive risk analysis using machine learning in the financial sector.	This research focused on measuring and assessing systemic financial risk using machine learning techniques.	Survey	Kou et al. (2019)
46	Sustainable Industry 4.0 framework development.	This study developed a sustainable I4.0 framework by identifying automation and process safety, economic sustainability, and environmental preservation as key I4.0 research areas.	SLR	S. S. Kamble et al. (2018a)
47	Analysis of the influence and dependence on I4A-restricting obstacles in the Indian industrial sector.	Deployment hurdles for I4.0 have been identified.	ISM Fuzzy MICMAC	S. S. Kamble et al. (2018b)
48	Analyzed the role of workforce 4.0 in advancing I4.0 and offered a road map from the perspective of operations management.	Constructed a structural model to specify the standards for choosing the workforce in the I4.0 environment.	FDEMATEL	Kazancoglu and Ozkan-Ozen (2018)
49	Analyzing the use of cutting-edge digital technologies for manufacturing.	Investigating and evaluating advanced digital manufacturing technologies within the context of I4.0. This study found that supply chain management's use of digital technology significantly impacted production principles.	FAHP, PROMETHEE	Medić et al. (2018)
50	I4.0, through an organizational interoperability perspective.	This study discussed the case of the automotive supply chain.	DEMATEL, PROMETHEE	Gomes et al. (2018)
51	Implementation issues of risk management for I4.0.	Framework supporting framework for I4.0 adoption of risk management	Literature Review	Tupa et al. (2017)
52	For the analysis of financial risk, clustering	• Three sets of financial risk data were clustered	TOPSIS, DEA,	

SN	Contributions	Study Findings	Tools Used For Analysis	Literature Support
	techniques are evaluated.	using six different techniques. • The clustering algorithms are ranked using three MCDM techniques using eleven performance criteria.	VIKOR	Kou, G., Peng, Y. and Wang (2014)

To address the research question, 'What is the direct and indirect impact of I4A on SOP?' researcher has conducted extensive explorations based on prior studies and discussions with experts. Researcher found dearth of studies which could clearly establish the direct or indirect relationship among I4A on SOP, which is discussed further. This has paved the way towards development of much required model I4.0 adoption model.

2.7 Research Gap Identification

I4.0 is a relatively new and evolving field in the manufacturing industry; thus, many potential research gaps are emerging. Future studies may focus on the following topics based on the literature's identified research gaps:

1) Absence of a Robust I4.0 Research Framework

The I4A has significantly aided in achieving operational excellence and overall organizational sustainability, according to all the big-scale businesses and a select few medium-sized businesses that have already adopted the I4.0 vision in their business operations. The first mover's experiences encourage others to follow the same route. Therefore, there is a good possibility that I4A will eventually benefit Indian manufacturing enterprises. Even while it seems achievable, it is true that without a strong framework for addressing the obstacles and impediments to these new breakthroughs is crucial.

In spite of the numerous published I4.0 conceptual frameworks, it appears that this issue has not yet been thoroughly envisioned, addressed, and empirically evaluated from an organizational awareness and technology perspective. Few studies have examined region-specific enablers and inhibitors to I4A in the context of geography, politics, culture, and business practices from a Leen-Green viewpoint (Bonilla et al., 2018). The majority of frameworks overlook key I4.0 drivers like organizational strategies, capital investments, stakeholders like customers and employees, I4.0 regulations, and significant new technologies (Tortorella et al., 2021). The frameworks already in place also don't outline a systematic, step-by-step process for embracing I4.0. Herein lies an opportunity to create a framework that is simple to use and includes the framework investigating the interrelationship among I4A, DC, CEP, and SOP, which is precisely an organization's ultimate goal. Decision-makers may find it simpler to understand the complex linkages using the framework between I4A, DC, CEP, and SOP attributes and the current state of I4.0 preparedness. Managers can also quickly identify their businesses' current advantages and disadvantages compared to competitors by balancing their inherent organizational capabilities and optimum resource utilization.

2) **Missing Comprehensive Analysis of I4A, CEP, DC Drivers Enablers, Risks, Inhibitors, and Key Performance Indicators**

Inhibitors, enablers, drivers, KPIs, and risk assessment were not addressed in previous studies clearly and comprehensively, as was pointed out in the literature review (Parhi et al., 2021). These studies either disregarded the expert's interventions, leaving them mostly irrelevant due to condensed solutions, or they just minimally considered the challenges, barriers, restricted risks, and KPIs. Furthermore, the dearth of research on I4.0 risk assessment and I4.0 KPIs in a unified model motivates the researcher to take this into account and design a long-term I4.0 model for the manufacturing businesses of India. After reviewing the literature, researchers discovered that relatively few works highlight the risk-related problems businesses face as they embark on the I4.0 vision. Of the lack of academic research, decision-makers were unwilling to take the initiative and engage in the digital revolution. Thus this study will allow future studies to develop an analytical framework or model to assist them in considering it as a foundational base. By collaborating with specialists, researchers, and decision-makers, the researcher proposes that the study has to be taken steps to counteract the constraints of prior research to present the most appropriate, practical, ideal, and practicable solution.

3) Minimal Number of the Exploratory Studies

Numerous articles addressed the advantages and potential drawbacks of I4.0 for established enterprises (Kamble et al., 2018b; Liao et al., 2017). There aren't many exploratory studies, nevertheless, that examine the benefits, challenges, and potential effects of modern technologies on many aspects of enterprises in developing nations. Future studies may focus on examining the major barriers to I4A, the advantages of I4.0, and the potential effects of emerging technologies, I4.0 drivers, DC, and CEP drivers, and their impact on the performance of manufacturing organizations in developing countries like India (Lopes de Sousa Jabbour et al., 2018). Due to this, the researcher suggests creating scientific business transformation methods and KPIs, drivers of DC, CEP drivers, and SOP. Then, it should be properly validated by a number of case studies as the I4.0 interrelationship analysis of the I4A, DC, CEP, and SOP to resolve real-time difficulties has been the subject of very few investigations.

4) **Minimal Number of the Empirical Studies**

Despite the fact that the literature has shown that I4.0 can enhance firm performance, the majority of studies (Chauhan et al., 2021; Szász et al., 2021) have focused on the I4.0 impact on operational performance, completely downplaying the potential impact of prospective I4A, adoption of CEP and building DCs for SOP needs to focus on the empirical study. There aren't any empirical studies, or there are only a few dispersed ones, the researcher could find (Chauhan et al., 2021; S. Kamble et al., 2020) that could be used to consolidate, evaluate, scrutinize, and confirm a significant association between drivers of I4A, DC and CEP to SOP, and a mediating relationship of DC and CEP. Thus, addressing this issue for the current research is a distinct addition to this study.

In light of the mediating role of DC and CEP on the relationship between I4A and SOP I4.0, which is based on contingency and DCV theory, the current study is one of the pioneers in examining the relationship between I4A, DC, CEP, and SOP. The identified research gap helps to address the study's earlier research issues.

5) As shown in the SLR, the majority of empirical research has adopted strategic or conceptual approaches, with only a handful using qualitative and quantitative methodologies that are theoretically grounded.
6) Indeed, the I4.0 would quickly gain traction in Indian manufacturing firms. COVID-19 has undoubtedly and partially increased urgency. Therefore, in order to make the most of this situation, we must have a thorough yet simple framework. The adoption of I4.0 will undoubtedly proceed more smoothly if

key KPIs, the most significant I4.0 risks, and their interaction are studied and analyzed. On a related point, the researcher has discovered several gaps in the previous study that failed to address the most important I4.0 threats.

Thus, the researcher suggests that the integrated model development for investigating the relationship between I4A, DC, CEP, and SOP and its validation is guaranteed to be robust and useful in supporting the current and foreseeable demands of I4.0 aspirant company challenges. This way, the study stands significant and adds value to the body of new literature.

This studies' one of the prime objectives is to provide viable, feasible and sustainable I4.0 adoption model to the Indian Industries (Manufacturing) which will ensure sustainability in long run. This objective has been very well addressed by garnering supportive arguments from the existing studies. To the best of the explorations and understandings, the earlier research lag in validating of respective the derived models. Hence, the research question addressed here was the need and urgency of the time. The research question addressed is, 'How do we develop and validate a sustainable model for I4A to earn sustainability and a competitive edge in the volatile market?'.

2.8 Conclusion

This chapter examines current evidence in the literature, focusing on the fast-growing and highly multidisciplinary I4.0 research domain. It provides a qualitative literature review of the I4.0 field as well as the findings of a quantitative study. The study themes concerning I4.0 in its manifestation are addressed, as are the topics impacting I4A, its advantages, enabling technologies, challenges, and opportunities. A data-driven quantitative strategy using bibliometric analysis and SLR methodology to conduct qualitative analysis was used in this work. The quantitative literature review has made three significant contributions to the corpus of literature on I4.0. First, it provides a thorough overview of this topic in the form of well-known research areas, top research themes, authors, countries, and highly referenced publications. It also exposes the study methodology and trend analysis of the main topics and themes. The results of the bibliometric analysis are compiled in the third phase.

The findings of the quantitative literature evaluation using the SLR study demonstrate the systematic process used to define the specific problem and the practical importance of the identified constructs for the current study's model development. The important constructs I4A, DC, and CEP, as well as their drivers, are finalized as a result of this step. In order to further expand the study problem, it is necessary to look into the drivers of I4A, DC, and CEP, as well as their connections to the SOP. The current status of I4.0 in manufacturing, SC, lean-green manufacturing, CEP, DC, and SOP, along with government initiatives in I4.0 progression at the national and international levels, are also narrated in detail in this chapter. This knowledge aids the researcher in narrowing the study focus and determining the appropriate research gap.

It offers useful information that practitioners can use to better comprehend the knowledge in the I4.0 paradigm. As a result, the chapter gives practitioners and decision-makers an understanding of the crucial criteria and requirements of I4.0. Additionally, the subjects covered by the trend analysis include details on the crucial areas in which businesses, governmental entities, legislators, users and suppliers of developing technologies, CEP practitioners, and DC developers should concentrate to acknowledge I4.0 successfully. The study's findings might be used from a managerial standpoint to fully grasp the elements of I4.0, DC, and CEP and emphasize SOP's significance.

Thus, to validate this study's urgent need and analyze the contributions, tools, and approaches of various studies, a thorough examination of the current research landscape related to the topic under consideration is carried out religiously.

3 Research Methodology

3.1 Introduction

The research methodology adopted for this research is thoroughly explained in this chapter. Based on current ideas, models, and procedures, a systematic and scientific approach is taken to learn about the unknown. The chapter is organized into further detail about the research strategy, data collection methods, and methodology used to accomplish the research objective and respond to the research questions established in the first chapter. **Figure 3.1** shows the general research plan. The research study design is divided into two parts to achieve the study's objectives and research questions. The first stage involves doing exploratory case studies to gain a broad grasp of how I4.0 is perceived from the standpoint of an Indian manufacturing organization. Additionally, studying the most recent advancements and I4.0 preparedness to understand the significance of I4.0 KSFs, KPIs, and risks and expanding it to identify the most important constructs for the current study and designing a survey questionnaire to conduct a survey focusing on Indian manufacturing companies. The purpose of survey conduction is to validate the conceptual model that has been built, aiming to provide the roadmap to the stakeholders for advancing I4.0 to achieve SOP.

3.2 Research Plan

The systematic process for integrating research techniques and data analysis is referred to as a research plan (Arseven, 2018). The research selection has undergone several discussions and validations. The primary requirements were the need for research and the viability of the available tools. The research plan, as shown in **Figure 3.1,** demonstrates the deployment of a combination of methods to carry out the current study. The body of existing literature was reviewed with the aid of quantitative and qualitative techniques. First, bibliometric analysis was used to examine and synthesize the literature in the I4.0 sphere in order to identify the main study topics and key themes. Further, the SLR was undertaken to finalize the survey problem, constructs, subconstructs, and testing and validity of the developed framework. The comprehensive qualitative literature review focuses on the evolution of the I4.0 concept, emerging technologies, the current status of I4.0 in Indian and global perspectives, current progression in research areas in I4.0, and tools, techniques, and underpinning theories considered in the extant literature to address research problems in these emerging areas. The review is further extended to identify potential benefits of I4.0, opportunities, barriers, risks, KSFs, and KPIs; finally, the research gap is extracted and elaborated in detail in **Chapter 2.** The exploratory case study approach followed further is described ahead. The following dimensions were also taken into account for the analysis of the survey results and further explored in **Chapter 6.**

- To quantify the magnitude and direction of the relationship among constructs, subconstructs, and items.
- To explain the inter and intra-relationship among the sub-constructs and main constructs.
- To generalize the findings beyond the sample units.
- To develop the robust and sustainable I4A model
- To validate the model and make it industry ready.
- To explore the long-term possibilities.

3.2.1 Exploratory Case Studies

Exploratory research is a study carried out first to explain and outline the problem's description (Babin et al., 2015). It is defined as an experimental study intended to improve knowledge of a topic, get clarity, characterize the nature of the problem, and/or determine the essential factors that must be researched (Gates and McDaniel, 2013). Before a prototype for the study design is set up for a complete inquiry. However, this type of approach was performed as a first step to guarantee that the study was essential and conclusive.

This approach is undertaken to study a scenario that is unknown or where there is no information available about previously solved difficulties or research themes (Bougie and Sekaran, 2016). A case study approach offers more favorable outcomes than other techniques in the scenario of a lack of empirical research, the complexity of the phenomenon, and the dearth of valid definitions and measures (Yin, 2009). Thus, it is required for exploration that aims to delve into uncharted territories of the I4.0 revolution (Jiang, 2018), due to the paucity of research in these areas. The researcher chose it to obtain a deeper knowledge of the concept and to study all facts related to the research challenge. The three techniques for utilizing this approach are interrelated: (1) diagnosing a condition, (2) evaluating options, and (3) uncovering new ideas (Babin et al., 2015). Thus this study uses exploratory case studies to understand firms' I4.0 preparedness, perception, and knowledge and how Indian industries perceive I4.0 components. It is recognized as an essential tool for gaining knowledge about what is going on, and it is known to be flexible and adaptive as new information becomes available.

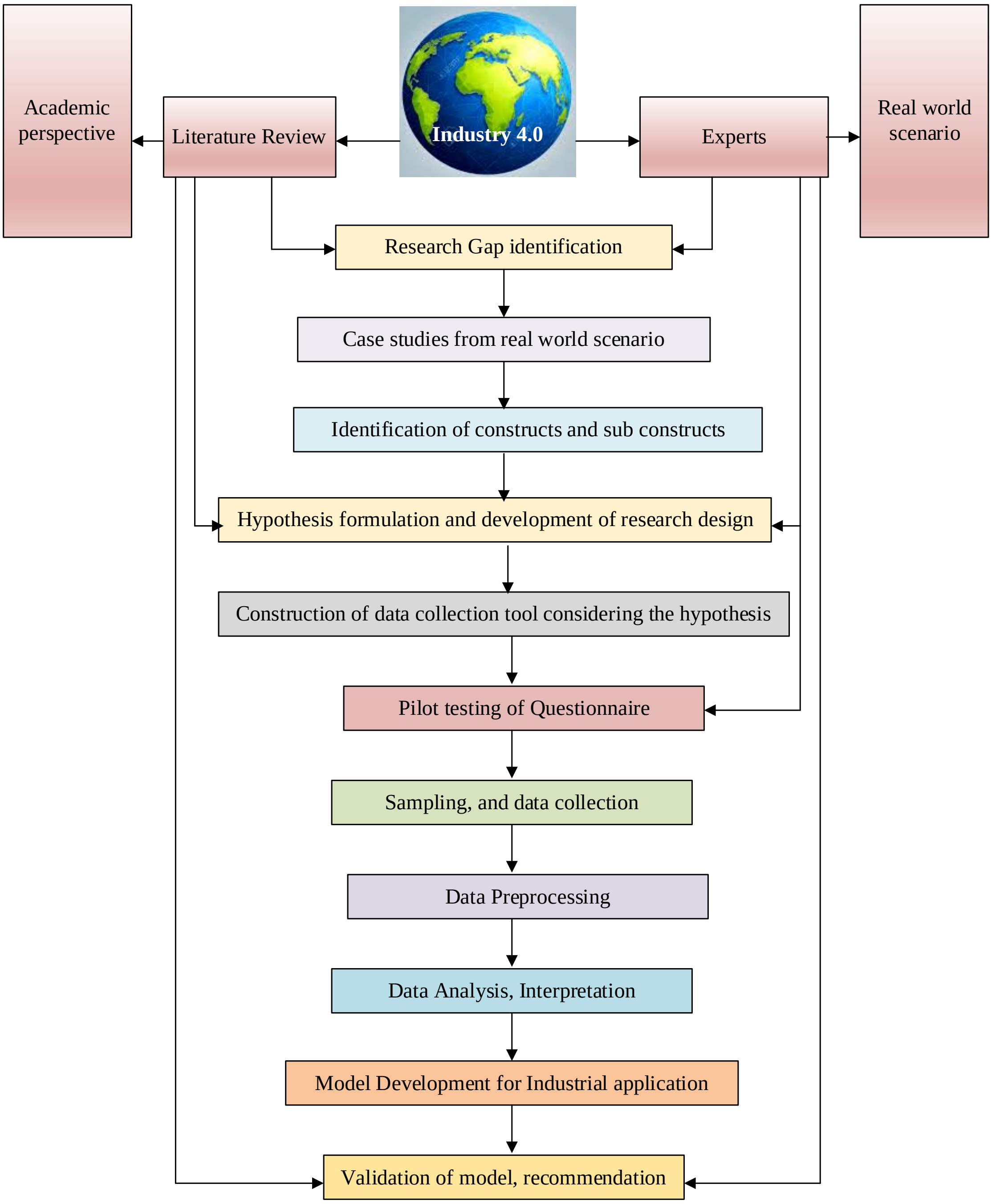

Figure 3.1: Research Plan Adopted in the Study

Investigative case studies in manufacturing organizations were carried out in this context. Two case studies were chosen for this study, and the experts were identified from a database that had already been prepared and met the selection criteria. The researcher adopted the focus group consultations and interviews to understand better the issues under consideration for research to carry out the investigations in this study. As a result, the researcher used this approach to gather information about experts' experiences with the I4.0. This study has immensely benefited since it helped the researcher advance the hypothesis on the research issue. It enables a researcher to obtain information from a small sample group of people (Cooper and Schindler, 2012). This study used a multi-method strategy that combines qualitative and quantitative approaches; in this case, exploratory research is linked to the qualitative method. Thus this approach is essential for gathering qualitative data through structured and semi-structured interviews (Lewis et al., 2016). The expert's data is gathered through interviews, while the company representatives are sent the questionnaire link. The researcher benefited from discussions to acquire relevant information from the experts, who could discuss their work experiences with I4.0 projects. The outcome of the exploratory case studies led to the finalization of constructs and sub-constructs considered for the further empirical analysis. The procedural steps adopted for the conducted case studies, selection of case studies, data collection procedures, experts' credentials, tools and techniques used (MCDM methods), case analysis and reporting of the results, and discussions on the findings are discussed in detail in **Chapters 4 and 5.**

3.3 Identification of Constructs, Subconstructs, and Measuring Indicators

The outcomes of the case analysis were then used to identify the constructs and subconstructs and develop hypotheses for the proposed developed research framework. The quantitative and qualitative LR presented in **Chapter 2** demonstrate that while I4.0 knowledge and awareness are expanding, there is still a long journey to go. The SLR emphasizing the earlier research in this area reveals that there is still a tremendous amount of unrealized potential for I4.0; therefore, its implementation is still in an early and transitional period. In view of this, the researcher merged the newly created scale with the previous scale, then engaged in discussions with the experts to assess the constructs and subconstructs measuring indicators (Churchill, 1979). This study considered only extremely important and substantial constructs (latent variables), and the measuring indicators that correlate with them have been taken into account. Before being approved to measure the constructs, these measuring indicators are painstakingly updated, changed, and evaluated for validity, credibility, and consistency by proficient industry professionals and academics who are well-versed in technical and managerial expertise.

To the identification, the extracted construct I4A supported by DC and CEP leads to SOP in the context of Indian organizations in terms of the recommendations from comprehensive LR and exploratory case studies, and the relationship between their subconstructs is not measured and examined. This underlines the importance of using a framework that has been properly validated by empirical data, which is a significant component of this study. The current study addresses this need by highlighting Indian manufacturing organizations and empirically examining the impact of I4A on SOP under the integrating influence of DC and CEP. Additionally, this study sought to look at the relationships between I4A, DC, and CEP, as well as those between I4A and DC, DC and CEP, and CEP and SOP, in an effort to address the crucial problem of a lack of literature in emerging nations such as India. The details on the constructs, subconstructs, and measuring indicators are described in **Appendix 1.**

3.4 Formulation of the Theoretical Model and the Hypothesis Development

In this incredibly dynamic, unstable, and competitive business environment, organizations need to acquire a competitive advantage in order to become sustainable. This can be feasible through optimum utilization and allocation of resources and capabilities that are already in place, reconfiguration of knowledge assets, and developing competencies to deal with the fierce demand of contemporary industries. Therefore, business executives, decision-makers, and researchers must carefully channel and strategically plan the selection and use of resources and capabilities, considering their importance and value in impacting the overall business system. As a result, developing a credible, practicable, and substantial framework in this unstable business ecosystem for DCs allocation and deliberation is the only reasonable option (Teece, 2014). At the same time, the integrity of the natural environment can not be overlooked; thus, the crucial consideration of the CEPs must be the prime objective while moving ahead during and after the I4A (Edwin Cheng et al., 2021). The theoretical model introduced in the current study describes the relationship between I4A, CEPs, and SOP depicted in **Figure 3.2,** which is a unique contribution to the extant literature and validated through meticulously conducted SLR. This is backed up by an empirical study considering Indian manufacturing companies to respond to the formulated research queries. Owing to this, the researcher has designed and formulated the following hypothesis to respond to the derived research questions.

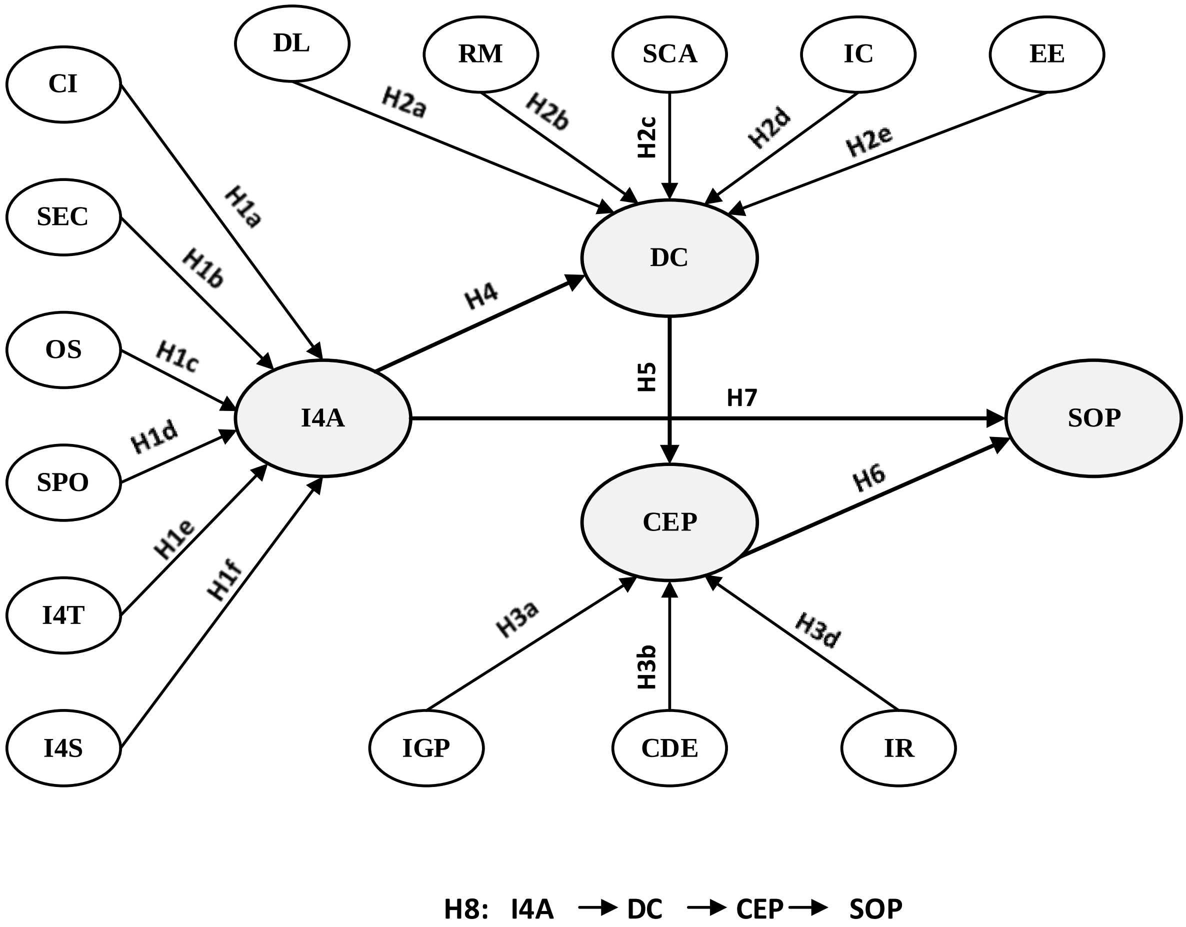

Figure 3.2: Conceptual Research Model

3.4.1 Capital Investments and Industry 4.0 Adoption Association

The uses of digital technologies have been escalating day by day, urging the need for substantial capital investments in various domains of the manufacturing organization and placing pressure on stakeholders to secure the necessary financial resources. Eventually, the customers' expectation of customized products at lower cost adds to the challenges of I4A, marking financial investments as one of the major challenges (Sony et al., 2021). Nevertheless, amid the anticipated instability, exorbitant cost, ill-defined return on investment, and inadequate assurance concerning this new transition, most companies are concerned about the unpredictability of the payback period. Also, substantial financial commitments in I4.0 technologies and building associated compliant digital infrastructure demands attention and tends to increase the dilemma regarding the decision-making related to capital investments in I4A (Benitez et al., 2020).

In spite of this still, several organizations have taken this as an opportunity and started adopting I4.0 practices and initiating capital investments towards its adoption, looking forward to its projected benefits to become competitive in the globally competitive business landscape (Fayomi et al., 2020). According to Luthra et al. 2020 transformation of the entire supply chain's digitization and its many operations can be integrated, providing responsiveness and provenance at every stage of the entire value chain. This increases confidence between businesses and consumers, which favorably encourages financial investments for the I4A. Thus, it is observed that capital investments are one of the prominent drivers in I4A, and the earlier literature has addressed both its positive and negative implications on I4A, instigating the researcher to propose the following hypothesis:

H1a: Capital Investments (CI) significantly positively impact Industry 4.0 Adoption (I4A).

3.4.2 Stakeholders as Employees and Customers and Industry 4.0 Adoption Association

The basic foundation of I4.0 is on the collaborative, consistent, and seamless functioning of an organization's virtual and physical environment in the advent of the emerging digital landscape. Thus addressing this consideration, the existence of the human role is very important in this expected collaboration and integration to reach out to this main concern through the amalgamation of physical and virtual resources (Ghobakhloo, 2020). The potential to bring the entire manufacturing organization's mechanism to a remarkable intelligence level comes with the human-administered closed-loop supply chain that is virtual and has a valuable feedback system. The synergistic integration of human resources with AI while approaching the CPS system installations and cloud computing platform adoption resolves this efficiently and effectively (Longo et al., 2017). Owing to this, to trigger the widespread I4A, trained competent employees who have acquired dedicated technical skills and expertise on the shop floor and in the management team are a must (Fayomi et al., 2020). Thus the systematic integration of I4.0-infused virtual space with human elements can lead to surmounting the challenges of digital transformation and will encourage and support employees to become competent in the new requirement of I4A by focusing on sharpening their skills and competencies (Neumann et al., 2021). At the same time, this also necessitates urgent attention that due to the increased uses of autonomous and humanoid robots in automated manufacturing industries, there will be a huge crisis of skilled manpower to sustain the transitory requirement of I4.0 requirements. As a result, leading to increased work pressure and fear of losing employment, perceived the I4A negatively (Antony et al., 2021). In addition, due to the abrupt Covid-19 pandemic eruption, the reskilling and upskilling of employees at all levels of an organization at a large scale has become compulsory and critical (Maisiri and Van Dyk, 2021; Malik and Pasha, 2022).

Enabling the assimilation of services based on customer data through the digitalization of systems for customer support and assistance will support them in connecting with the organization's production system. This would also help them to avail the facility of tailored products made to their specifications and interests (Narula et al., 2020). As a result, companies will continue to offer highly customized products to clients while controlling costs and providing product quality (Müller et al., 2018a; Wang et al., 2017). The other side of it also needs to be considered that the inclination of the customers is towards not paying extra costs for the products and services which use the features of AI, IIoT, and other I4.0 technologies. Additionally, this could change based on the customers' paying capacity, awareness, and specialized requirements at individual levels (Kiel et al., 2017). While to accomplish this, the organization must constantly be aware of market trends to update its resources. This requires integrating the company's digital platform with the customer interface, which attracts more investments, digital infrastructure, and time to enable it to inform and acquaint its customers through effective communication mechanisms. This leads to a change in the organization's perspective negatively toward I4A. Thus, considering this fact, the researcher believe it is important to acknowledge the significance of the relationship of stakeholders as employees and customers involvement in accelerating I4A, so the researcher has proposed the hypothesis is as follows:

H1b: Stakeholders as Employees and Customers (SEC) involvement significantly positively impacts Industry 4.0 Adoption (I4A).

3.4.3 Organizational Strategies and Industry 4.0 Adoption Association

The driving force behind the implementation of I4.0 is the development of effective organizational strategies that enable enterprise information resource management systems with efficient employee involvement from a variety of areas of expertise, improving the decision-making process (Mittal et al., 2018b). The organizational strategies to stimulate digital transition and its fast-paced acceptance through the use of the latest I4.0 technologies, promoting leadership, and developing synergy with business partners leading to optimized utilization of resources accelerate the I4A (Akdil et al., 2018). Viable I4.0 deployment relies on matching I4.0 objectives with organizational strategies. I4A will therefore be facilitated by carefully designed organizational strategies that enforce customer integration in product design, increase resource productivity, enable product personalization through the use of decentralized and adaptable manufacturing, improve human-machine interface efficiency, and encourage collaborative work environments (Sony et al., 2021).

Nevertheless, developing organizational strategies that are I4.0 compliant is a challenging task. This demands a lot of employee brainstorming to change their mindset and work culture, as well as redesigning workspaces, rearranging the current infrastructure, and concentrating on research and development facilities that may see the I4A adversely (Sima et al., 2020). The researcher has established the following hypothesis to assess these viewpoints:

H1c: Organizational Strategies (OS) have a significant positive impact on Industry 4.0 Adoption (I4A).

3.4.4 Smart Products and Operations and Industry 4.0 Adoption Association

The adoption of smart products and operations is one of I4.0's central aspects. Integrating customer data within the organizational production system helps improve customer satisfaction and enables product approachability to provide customer flexibility. Thus smart operations are crucial in improving product performance, enhancing product features, and shaping value-added activities and processes (Dalenogare et al., 2018). Similar to this, the smart product's integration with a physical environment in virtual cyberspace in the underlying production system allows it to self-monitor, self-organize, and self-control. This results in the best possible capacity utilization to respond in real-time, is added to leverage an organization's competitive

advantage, and ultimately speeds up the I4A (Sony and Naik, 2019). The intelligent product captures data throughout its entire product life cycle by connecting to machines, sensors, cloud platforms, GPS, RFID, and other devices. It then uses real-time data analytics and machine learning algorithms to extract insightful information that aid in facilitating and ingraining the needs of the customers into the product during the process itself (Schmidt et al., 2015; Sony and Naik, 2019). Therefore, manufacturing organizations can easily consider implementing I4.0 in their organization if they have established smart products and operations in their value chain (Antony et al., 2021).
Although this is true, factors such as high product personalization, reduced product lifecycles, dynamic market demand, exorbitant financial and other resource investments, competent technology requirements, competitive pressure, and ambiguous long-term return on investment raise concerns about the feasibility of embracing smart products and operations (Bag et al., 2018; Telukdarie et al., 2018). Enyoghasi and Badurdeen (2021) argue that the literature is scarce in past studies directing the significant impact of smart products and operations on successful I4A while considering product, operations, and process integration to enhance the productivity of an organization. In light of this, the researcher believes that exploring the link between smart products and operations with I4A is essential. Hence, the proposed hypothesis is as follows:

H1d: Smart Products and Operations (SPO) significantly positively impact Industry 4.0 Adoption (I4A).

3.4.5 Industry 4.0 Technologies and Industry 4.0 Adoption Association

One of the major factors driving I4A in a manufacturing company has been the usage of I4.0 technologies in different industrial processes (Basl and Doucek, 2019). Collaboration across major I4.0 technologies, including BDA, CC, IoT, AR, VR, autonomous robotics, applications of AI, and ML, as well as integrating with companies' end-to-end, horizontal, and vertical value chains, plays a positive role in pushing I4A expedition (Kang et al., 2016). Thus, such technologies exchange information with other connecting devices, contributing to the emergence of an intelligent manufacturing system (Frank et al., 2019). Sensors in IoT devices and computational power communicating wirelessly with other connected devices in cyberspace offered real-time decision-making through rapid information processing and secured information retrieval remotely (Tao et al., 2018). CC platform can store enormous amounts of data on the internet server. It has the potential to process it to extract valuable insights and facilitate its access and retrieval without any additional requirement of physical infrastructure. Also, coupling IoT with the CC platform enabled with BDA ability help in gaining interesting and potential revelations based on the data obtained from the linked equipment and machinery (Frank et al., 2019; Lu, 2017). BDA may effectively manage the societal issues of the stakeholders (consumers, staff, administration, etc.) by tracking and predicting their attitudes and cognitive styles. This makes it possible for people to participate in resource usage optimization more effectively (S. A. R. Khan et al., 2021). As per the argument of Edwin Cheng et al. (2021), even though the BDA supports CEPs and promotes the supply chain more sustainably, strengthening its competitive capabilities is challenging. Also, its implementation will encourage team management, but the possibility of positively impacting innovation processes, eco-friendly product development, and supply chain advancements can not be assured (Bag et al., 2021b).

Repetitive tasks and non-value-added manufacturing process automation improve productivity, adaptability, and accuracy. The uses of AR and VR are an essential part of I4A. They allow the employees to reach the critical components of the mechanical assembly during the maintenance process by accessing digital information and coupling it to the physical environment through appropriate employee training (Egger and Masood, 2020). These practices are frequently preferred in inspection, supervising logistic operations, production assembly line monitoring, human-robot coordination, and controlling (Marino et al., 2021). Although each of these points is valid, I4.0’s development is still hampered by technical limitations (Bhuiyan et al., 2020). For this, companies must considerably expand technological facilities to increase their I4A strength (Hizam-Hanafiah et al., 2020). Thus, to rectify the various viewpoints on I4.0 technologies shown in recent literature affecting I4A, the researcher has come up with the following hypothesis:

H1e: Industry 4.0 Technologies (I4T) significantly positively impacts Industry 4.0 Adoption (I4A).

3.4.6 Industry 4.0 Standards and Industry 4.0 Adoption Association

The secured I4.0 standards focused on social aspects providing the centralized IT infrastructure capabilities to promote research and development to encourage innovations and build trust in stakeholders in moving forward for the investments in the I4.0 technologies adoption. The well-defined universal I4.0 standards guidelines for I4.0 implementation practices can encourage try-on pilot scheme design, international collaboration, and other joint ventures to manage financial and digital infrastructural concerns and can be readily dealt with and observe I4A positively (Morisson, A. & Pattinson, 2019). Due to the absence of concrete I4.0 norms for benchmark architectural progress, compliant IT and digital infrastructure deployment, and legal abidance management guidelines will delay the I4A process in the manufacturing organization (Chauhan et al., 2021).

I4A is expected to handle many processes, data, and information exchanges in the communication network, necessitating an end-to-end encrypted communication system that needs strong legal and regulatory support for I4.0 standards development in place (Ng et al., 2022). Even most manufacturing organizations are confused about embracing I4.0 due to the lack of clarity on I4.0 standards (Luthra and Mangla, 2018). Thus, researchers thought it might be interesting to investigate the connection between I4.0 standards and I4A. Hence, the proposed hypothesis is as follows:

H1f: Industry 4.0 Standards (IS) significantly positively impact Industry 4.0 Adoption (I4A).

3.4.7 Digital Leadership and Dynamic Capabilities Association

Digital leadership refers to the ability of organizational leadership to create a balance between the changes that occurred due to an emerging company function’s digitalization with the resistance to this change by existing resources through handling it effectively. The association of DC with the appropriate digital leadership within the organization seeking to implement I4.0 to sustain a fierce business environment would enhance its potential performance (Witschel et al., 2019). There is a need to understand the requirement of developing the digital infrastructural, human-oriented, and other resources leading to the building and exploring the ways of developing the organization’s DCs compatible with it; the role of digital leadership is vital (Sasmoko et al., 2019).

Still, there are the scares literature on DCs and their alliance with digital leadership, leaving the scope for exploring it to understand its potential to improve an organization's DCs, leading to a competitive advantage (Karippur and Balaramachandran, 2022; Mihardjo et al., 2019). Hence, the proposed hypothesis to address these most significant concerns is as follows:

H2a: Digital Leadership (DL) has a significant positive impact on Dynamic Capabilities (DC).

3.4.8 Risks Mitigations and Dynamic Capabilities Association

An adequately designed risk mitigation mechanism emphasizes developing an organization's culture, processes, and capabilities concerning the economic, social, and environmental risks to respond in real-time situations and enhance an organization's DCs. Risk mitigations leading to improvement in an organization's DCs must be evaluated holistically and structured in an appropriate framework to achieve a competitive advantage (Snieška et al., 2020). Various sources of risks and their unavoidable effects on DCs can be prevented by strengthening their mitigations to encourage DCs (Yu et al., 2019).

In new training and development initiatives, massive financial investments are required, creating hurdles in economic risk mitigation (Sima et al., 2020). A sustainable society becomes unbalanced as a result of management policy changes, addressing resistance to new business models, and reorganizing existing employees generate social risk mitigation concerns (Antony et al., 2021). The virtual or physical infrastructure required to improve CEPs and I4A results in huge energy consumption, and the management of manufacturing organizations has not received a clear notion to handle them effectively. This has produced confusion in adopting environmental risk mitigation strategies (Amjad et al., 2020). All these pointed towards considering these mentioned risks mitigations otherwise would have impacted positively to improve DCs of an organization perceived adversely. Thus, this encourages the researcher to explore the link between risks mitigations and DC. Considering this, we propose the following hypothesis:

H2b: Risks Mitigation (RM) has a significant positive impact on Dynamic Capabilities (DC).

3.4.9 Supply Chain Agility and Dynamic Capabilities Association

DCs relates to an organization's ability to detect the prospective opportunities in the surrounding business setting and to seize them, providing the required changes in the existing organizational setting to promote organizational growth (Teece, 2007). Supply chain agility is pivotal to seizing the prospects of the marketplace as it allows the organization to sense the demand of the customers of the competitive marketplace and seize them to position the DCs as per the requirements in real-time through its agile response. Since supply chain agility is a core part of DC, it shouldn't be taken into account in isolation (Aslam et al., 2018). Supply chain agility reconfigures the company resources at the in-house and supply chain level, responding quickly and strengthening the company's DCs (Dubey et al., 2018). Even though this is true, it is observed that researchers in the past have centered on the connection between supply chain agility, adaptability, and performance only. But did not explore its alignment with companies' dynamic capabilities empirically (Awwad et al., 2022; Ramos et al., 2021); this inspires the researcher to consider the following hypothesis to explore the linkage between Supply chain agility and dynamic capabilities.

H2c: Supply Chain Agility (SCA) has a significant positive impact on Dynamic Capabilities (DC).

3.4.10 Innovation Capabilities and Dynamic Capabilities Association

A robust business model is based on the foundation of strong DCs where innovation capabilities are pertinent. The strategic innovation capabilities at the operational level enable innovation culture, optimum resource utilization, production functions collaboration, and employee capabilities development positively support DCs (Bocken and Geradts, 2020). Developing different innovation capabilities required huge investments in research and development resources, structured innovation programs, and training, adversely impacting the company's DCs (Rachinger et al., 2019). Continuous focus on improving the innovation capabilities responds promptly to the dynamic market demand and strengthens the DCs but requires updated research and development facilities, the latest digital technologies, and an alert management team, again hindering the progression of the DCs growth (Travaglioni et al., 2020). Minimal emphasis has been given to exploring the significance of innovation capabilities on dynamic capabilities in the previous literature that encourages researchers to investigate this link. Thus, addressing this intention, the proposed hypothesis is as follows:

H2d: Innovation Capabilities (IC) have a significant positive impact on Dynamic Capabilities (DC).

3.4.11 Employee Empowerment and Dynamic Capabilities Association

Facilitating employees' strategic and dynamic competencies progress enables their empowerment and elevates companies' DCs (Blanka et al., 2022). An effective change management initiative that considers the problems of the employees while not disturbing or pressuring them about the loss of employment and compatibility with new job requirements or jeopardizing the organization's interests can contribute to their empowerment and lead to handling the DCs of an organization efficiently (Siltori et al., 2021). Knowledge-sharing behavior of the employee develops confidence among the employees and acts as an intensive to boost DCs (Qader et al., 2022). Extensive employee engagement in the decision-making process, imparting more controls to them, providing training and skill development facilities, and continuously improving their performance uplift the employees' interest leading to enhanced DCs of an organization (Aslam et al., 2018). Thus identified, few studies in earlier literature motivate the researcher to examine the connection between employee empowerment and DCs. Hence, the proposed hypothesis is as follows:

H2e: Employee Empowerment (EE) has a significant positive impact on Dynamic Capabilities (DC).

3.4.12 Innovation in Green Processes and Circular Economy Practices Association

Innovations in green processes are achieved through energy-efficiently designed products; technology-enabled green manufacturing processes avoiding wastages act as a strategic tool to achieve sustainability in production processes. This helps in raising confidence in adopting CEPs by contributing to preserving nature's integrity (Fernando and Wah, 2017). The manufacturing industries' top priorities today are addressing the issues of climate change that are more urgently needed and taking preventive action to reduce waste and pollution. Greener innovations must be promoted in innovation processes to address this crucial issue (Imran and Jingzu, 2022) and enhance CEPs. The sustainability of CEPs can be measured in terms of the capability of an organization to facilitate innovation practices in increasing the greenness of the manufacturing processes (Suchek et al., 2021). There are minimal shreds of evidence available proving the significant impact of innovation in green processes on CEPs due to the limitation of resources available to encourage innovative approaches in industries and the lack of standardized guidelines to implement them (Imran and Jingzu, 2022). Focusing on this aspect, researchers felt the need to address the relationship between innovation in green processes and CEPs' significance as a priority. Thus, the researcher has developed the following hypothesis:

H3a: Innovation in Green Processes (IGP) has a significant positive impact on Circular Economy Practices (CEP).

3.4.13 Circular Dynamic Environment and Circular Economy Practices Association

A dynamic environment is an external variable that is difficult to predict the change outside of the company and is an integral part of DC. A circular dynamic environment can be described as inertia, which is a drive toward CEP via consumers, governments, and competitive pressures (Khan et al., 2020a). Thus the circular dynamic environment needs to be attended to urgently; when there is intense stakeholder pressure to adopt CEP, which impacts environmental capabilities (Scarpellini et al., 2020b).

A circular dynamic environment can be empowered by strengthening the external environmental capabilities related to enhancing CEPs. But it has not yet been explored to understand its significant impact on CEP, leaving the scope for extracting new insights into this relationship to integrate environmental responsibilities and its management accounting at various operational fronts in an organization (Burritt et al., 2019). Hence, the proposed hypothesis is as follows:

H3b: Circular Dynamic Environment (CDE) has a significant positive impact on Circular Economy Practices (CEP).

3.4.14 Investment Recovery and Circular Economy Practices association

Investment recovery is often affected by the increasing prices of the resources and their scarcity which is always unpredictable. CEPs emphasize the recycling, reuse of resources, and conversion into high-quality reusable products; reducing wastage poses a positive association of investment recovery with CEPs (Botezat et al., 2018; Edwin Cheng et al., 2021).

The company's initiative to offer rewards to the workers to promote environmental performance results in economic benefit and increase the prospects of investment recovery, eventually promoting CEPs. Very few studies have considered investment recovery a driver of CEPs (Masi et al., 2017; Q. Zhu et al., 2010). Consequently, to reach inferences about how investment recovery and circular economy are related, hence, the researcher has decided to propose the following hypothesis:

H3c: Investment Recovery (IR) has a significant positive impact on Circular Economy Practices (CEP).

3.4.15 Industry 4.0 Adoption and Dynamic Capabilities Association

I4.0 technologies and DCs jointly have the potential to offer organizations a competitive edge (Díaz-Chao et al., 2021). I4.0 practices facilitate the advance 10R manufacturing capabilities and strengthen the DCS of an organization (Bag et al., 2021a). The digital transformation is happening for I4A through IoT, BDA, CC, and blockchain changing business models, seizing the opportunities and challenges of disruptive technologies, and reconfiguring the internal and external resources. This has given a boost to empower the DCs of an organization yet has not gained significant attention from decision-makers and policymakers. It only emphasizes DCs impacting I4.0, but the reverse relationship potential might have the strength to be noticed (Warner and Wäger, 2019).

The earlier studies have provided evidence that I4A practices have improved organizational performance, productivity, real-time access, and continuous monitoring of the production system and value chain, enhancing customer relations through offering customization of products and customer involvement in approaching sustainability (Kamble et al., 2018a; Tirabeni et al., 2019). All these features of I4.0 are expected to improve the DCs of an organization. Thus, to verify this argument, the author has decided to consider the investigation of the relationship between I4A and DCs, which is missing in earlier literature. Referring to this, the researcher has proposed the following hypothesis:

H4: Industry 4.0 Adoption (I4A) has a significant positive impact on Dynamic Capabilities (DC)

3.4.16 Dynamic Capabilities and Circular Economy Practices Association

An organization's DCs are its capacity to grasp, identify, and reposition internal and external opportunities and challenges in the backdrop of embracing CEP. Referring to this, the knowledge and level of CEP adoption in the manufacturing industries are in the transition phase and do not assure success in achieving a competitive advantage. This emphasizes extracting more insights into the correlation of DCs with CEPs to balance the projected threats and opportunities of CEPs (Santa-Maria et al., 2022). Therefore, the relevance of DCs in CEPs requires comprehensive analysis as yet the framework to assess this relationship has partially, or very limited, touched the depth and has not developed considerable confidence among the stakeholders (O. Khan et al., 2021).

Although implementing CEP requires organizational transformation, it can be made simple with the right use of DCs. The emphasis on strengthening the DCs is desirable for CEP adoption (Khan et al., 2020b). Thus, to explore the vital DCs impacting CEP, it is essential to investigate this relation's significance statistically and empirically. Hence to address this critical concern, the proposed hypothesis is as follows:

H5: Dynamic Capabilities (DC) significantly positively impact Circular Economy Practices (CEP).

3.4.17 Circular Economy Practices and Sustainable Organizational Performance Association

Manufacturing organizations widely accept CEPs as they positively impact environmental performance by reducing environmental risk (Moktadir et al., 2018). Businesses incorporating CEPs into their operations have a good opportunity to surpass competitors and generate long-term profits by maintaining a dominant position in the market (Lahti et al., 2018). According to Lim et al. (2022), CEP is an essential component and facilitator to reaching sustainability goals to leverage SOP within a business; nevertheless, its implementation in manufacturing operations remains unnoticed. Although the implementation of CEP positively correlates with improving SOP in terms of environmental, economic, and social performance, it is critical to understand legal rules and regulations, making the investment in environmental and social projects more complex and expensive (Dey et al., 2022).

Manufacturing organizations' decision to establish various CEPs like lean manufacturing, green procurement, green innovations in processes, investment recovery, eco-design, and employee empowerment pointed toward the assurance of economic performance. Along with this, stakeholder pressure also influences this strategic decision. Additionally, numerous challenges such as clarity on customers' interest in environment-friendly products, insufficient information handling system, technical, infrastructural, and financial resource availability concerns, top management determination, government and public institutional support, and uncertainty related to job security are collectively resulting in perceiving CEPs' relationship towards SOP adversely (Prieto-Sandoval et al., 2018; Ritzén and Sandström, 2017). Thus, earlier studies have discussed the different perspectives on the relationship of CEP with SOP, instigating the researcher to verify these findings; Hence, the proposed hypothesis is as follows:

H6: Circular Economy Practices (CEP) significantly positively affect Sustainable Organizational Performance (SOP).

3.4.18 Industry 4.0 Adoption and Sustainable Organizational Performance Association

I4A has steered the modern manufacturing organization toward the sustainability goal in accordance with the triple bottom line (TBL) paradigm precisely defines sustainability as facilitating a balance between the objectives of the current and those of the coming generations concerning the environment, society, and the economy (Slaper, 2011). I4A proved economically feasible for consumers and organizations (Bauer et al., 2015). It has also shown potential in energy conservation, lowering energy use to maintain ecological equilibrium (Gobbo et al., 2018). All of that is accomplished by using smart products and services, cutting waste, controlling the disposal of harmful gases, and efficiently using time and resources, resulting in a contamination-free ecosystem (Lasi et al., 2014). I4.0 could boost effective and efficient resource utilization, which will help to increase environmental sustainability (Bonilla et al., 2018).

Real-time data accumulation and analysis are made possible by developing sensors, big data analytics, cloud computing, and IoT. This aids in monitoring production aspects that otherwise might damage the environment and harm eco balance (Dubey et al., 2019; Lu, 2017). It provides an opportunity to strengthen employee engagement and access to real-time data, minimize risk across resource efficiency, keep information handy, and preserve up-to-date information to increase the social survival of the organization (Huang et al., 2019). Job security is raised by intelligent human-machine interaction, which allows for remote work (Hossain and Muhammad, 2016). The TBL sustainable development goal is further complemented by utilizing I4.0 technical capabilities, techniques, policies, and adoption processes (de Sousa Jabbour et al., 2018; Harikannan et al., 2020). Braccini and Margherita (2018) argue that I4.0 improves performance and quality, decreases pressure and work overload, increases job satisfaction, and continuously monitors energy uses in real-time, all of which contribute to attaining TBL. According to Bonilla et al. (2018), I4.0 has both beneficial and detrimental effects on the sustainability of the environment.

Even though implementing I4.0 enhances SOP through uninterrupted connectivity, operational transparency, waste reduction, real-time tracking of the value chain through product, process, and systems collaboration and coordination, and socio-economic progress (Vrchota et al., 2021). Earlier literature has projected organizations' perceptions in a mixed manner because no solid framework demonstrates the link between I4A and SOP (Müller et al., 2020; Nara et al., 2021). Nevertheless, the absence of empirical studies that examined how I4A and SOP related within the context of I4A drivers led the researcher to develop the following hypothesis:

H7: Industry 4.0 Adoption (I4A) has a significant positive impact on Sustainable Organizational Performance (SOP).

3.4.19 Mediating Role of Integration of Dynamic Capabilities and Circular Economy Practices through Industry 4.0 Adoption Sustainable Organizational Performance

DCs impacting economic, social, and environmentally sustainable performance have the potential to achieve the sustainability goals of an organization (Díaz-Chao et al., 2021). Energy efficiency can be increased by integrating IoT devices with clean and sustainable energy monitoring features while operating in an internet network on the production line. Corresponding to this, techniques of additive manufacturing decrease resource usage, emissions, and waste while boosting performance, agility, and cost benefits (Kamble et al., 2018a). This embraces the business environment and economic sustainability performance, drawing attention towards I4.0 technology adoption that can strengthen the DCs and further activate the CEPs to produce the SOP. Thus, we believe reducing connected devices' deviant behavior and implementing preventative maintenance techniques re-empower DCs to embrace CEPs while effectively managing communication network failures and cybersecurity vulnerabilities.

While uses of smart glasses and wearable devices using AR, VR techniques deliberate secure working environment leveraging to sustain for the social performance. BDA, IoT, AI, and CC applications provide real-time data and information access to foster data-driven decision-making. This further enables entire value chain monitoring, connecting devices performance tracking, waste reduction, promoting recycled products, and focusing on customized and green products through understanding customers' preferences, ultimately controlling overproduction and increasing production efficiency (Li et al., 2020; Stock et al., 2018). Employees can manage physical stress and maintain mental stability by assigning bulky, harmful environmental tasks to robots. In addition, ergonomically constructed workplaces can avoid health issues associated with poor body posture and reinforced SOP (Gualtieri et al., 2020). This can help achieve RM, encourage DL, leverage ICs, and ultimately lead to EE contributing to boosting DC, leaving the scope for developing CEPs to leverage SOP. It is observed from the earlier literature, which has focused on the relationship between DC and SOP, I4.0 and SOP, and CEP and SOP (Bonilla et al., 2018; Dubey et al., 2019; O. Khan et al., 2021; Lim et al., 2022), and developed frameworks findings can not be generalized as they focused on an individual agenda. Thus, the researcher argues here that the facilitating integration of DCs and CEPs could possess the remarkable potential to extract new insights from the relationship between I4A and SOP, which we found missing earlier as no study has explored this relation statistically and empirically. Hence to verify and validate this in the Indian manufacturing setting, the researcher has devised the following hypothesis:

H8: Integration of Dynamic Capabilities and Circular Economy Practices positively mediate the indirect relationship between Industry 4.0 Adoption and Sustainable Organizational Performance.

3.5 Survey Methodology

A survey of empirical research design is mainly based on the data acquired primarily via questionnaires or structured interviews, either often (longitudinal research) or all at once (cross-sectional research). The goal is to collect quantitative or measurable data to uncover trends (Kara and Pickering, 2017). Survey research gathers information about or from individuals to characterize, match, and clarify their perceptions, attitudes, and behaviors toward the phenomenon being studied (Flick, 2015). According to Bougie and Sekaran (2016), determining the goals of the data collection, creating a legitimate and trustworthy survey data reception tool, structuring the survey document, incorporating the survey, maintaining and analysing the data collected from the respondents, and presenting a report on the results are all steps in the survey research process.. In this study, a questionnaire is used to obtain quantitative data for the study, which was done through survey research. The term “cross-sectional design” refers to a survey involving questionnaires and structured interviews (Leung, 2015). The data is then analyzed using statistical methods to identify patterns that different manufacturing organizations share. This examination of a representative sample of Indian manufacturing companies enables the researcher to draw conclusions about the study’s objective that are transferrable. A survey instrument was designed using the preliminary investigation and literature review findings. **Figure 3.3** illustrates the procedures taken during the questionnaire formulation process.

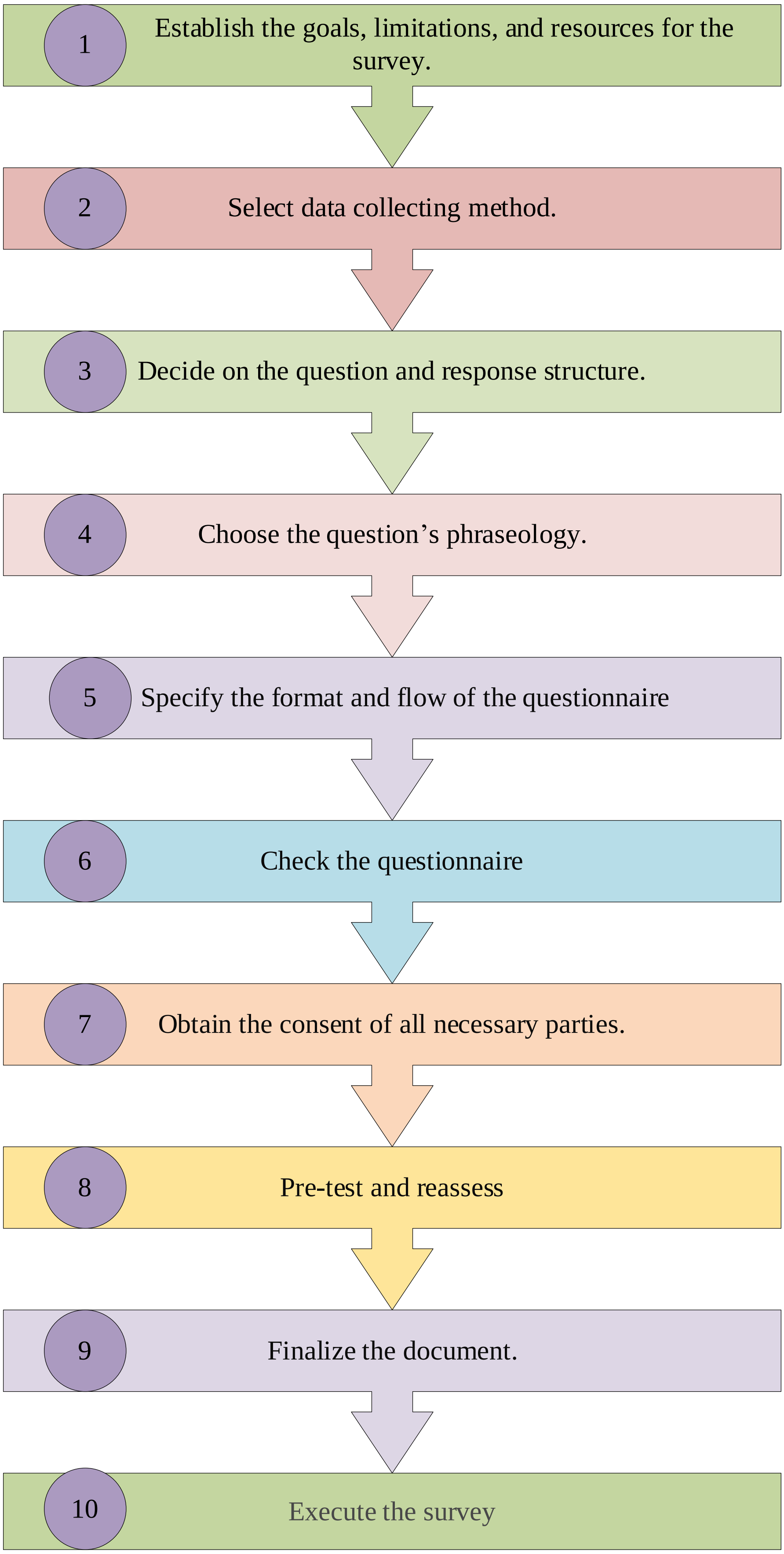

Figure 3.3: Process of Designing a Questionnaire

The followings are the stages used in the survey study:

3.5.1 Survey Instrument Development

The survey instrument's primary objective is to establish a framework for exploring the linkages between the key constructs I4A, DC, CEP, and SOP as well as the relationships between the drivers and these constructs. This leads to the development of an online version of the comprehensive questionnaire, which is then sent to all prospective respondents via email, in-person meetings, and social media platforms. When creating a survey instrument, significant effort was made to frame the questions in clear, intelligible language while maintaining the integrity of the theoretical content.

The questionnaire is intended to assess 61 different indicators in total. Data from the survey were gathered using a five-point Likert scale, such as 1 denotes a strong disagreement while 5 indicating a strong agreement, as shown in **(Appendix 1).** The chosen latent variables in this study were measured using the reflective scale (Diamantopoulos and Winklhofer, 2001).

A pilot study of the developed questionnaire is carried out before the survey to evaluate and ensure its accuracy, reliability, and content validity. Expert engagement and statistical techniques supported the inclusion and deletion of the final indicators in the current questionnaire version (Dillman, 1978). The credibility of the developed questionnaire ensured its viability for the intended purposes through the active involvement of fifteen experts from academia and industry with backgrounds in production and operations management, industrial engineering, information and communication dedicated to data and cyber security, and professional working experience and their active involvement in I4A projects.

A survey questionnaire was sent to 65 respondents from manufacturing enterprises in Maharashtra, India, as part of a pilot study to evaluate the validity of the designed research instrument. The measurement indicators with a Cronbach alpha (α) not more than 0.70 and demonstrated equivocalness were either eliminated, altered/corrected, or reevaluated. Aside from that, as shown by the final structures and contributing measurement indicators **(Appendix 1).**

3.5.2 Survey Sample Design

The researcher has chosen the non-random, purposive, and data collection method using snowball sampling from company representatives. This decision evolved after the discussion with experts and the referring past studies. The COVID-19 pandemic was the most significant constraint, along with the low rate of response to the questionnaire from Indian Industries. With the assistance of experts, a small number of professionals are initially chosen to make up the sample frame. These professionals are asked to share access to the questionnaire with others in their network who share a similar profile. By employing snowball sampling techniques, the researcher could contact the most trustworthy and convincing respondents, who also represented a larger target population group. Contact information for survey respondents is gathered from databases on government online portals, other organizations' websites, the professional network, industry alliances, I4.0 professionals forums, and connections in the industries.

3.5.3 Survey Administration

The questionnaire is served through email, WhatsApp, Telegram, Linkedin, and Facebook to 866 prospective respondents from 570 manufacturing organizations. The details of the sample profile are explained in detail in **chapter 6.** A sample size calculator was used to compute the sample size, which included a population of 280 respondents from 225 companies, a confidence level with 95 percent, a z score with 1.96, and a margin with error of 2. This sampling selection aims to create estimates faster by using a smaller sample size and ensuring that the outcomes are accurately predicted (Gates and McDaniel, 2013). The researcher confirmed that the participants were picked from the broader population that served as the foundation for the small sample based on their previous experience, depth of understanding, and expertise in the I4A, DC, CEP, and SOP in order to ensure that the prediction would be accurate in this study.

3.5.4 Survey Analysis

As Yin (2009) recommended, data analysis is "a systematic and ordered strategy adopted toward collecting the data so that information can be extracted from the data." When drawing conclusions from empirical data and going on to make generalizations, statistical evidence is essential. The SmartPLS 3.0 software suite and the IBM Statistical Package for Social Sciences (SPSS) version 23.0 were used to analyse the data obtained from the survey, as past studies have employed these software tools to analyze the survey data (Bag et al., 2018; Imran and Jingzu, 2022). The SmartPLS software package was also employed in prior investigations to examine the link between various constructs (Hair et al., 2012; Khan et al., 2019). For more details, refer to **Chapter 6.**

3.5.5 Partial Least Square Structural Equation Modeling (PLS-SEM) for Model Development

There are compelling arguments for employing PLS-SEM in this investigation. The researcher has primarily employed this technique for analysis and modeling since it consistently gives results, even with very little and non-normal data (Hair et al., 2011; Ringle et al., 2010). In a similar manner, the software SmartPLS 3.0 is carefully chosen for its capacity to understand the intricate cause-and-effect connection encompassing several pathways, constructs, and factors and develop a model (Hair et al., 2014; Sarstedt and Cheah, 2019). PLS-SEM scales down unexplained variance and enhances the value of explained variance for endogenous constructs, making it the technique of choice for assessing causal links in empirical studies. This prompted the researcher to adopt PLS-SEM to accomplish the objectives of the current investigation.

3.5.6 Hypothesis Testing Investigations

Utilizing both the inner (structural model) and the outer (measurement model) models, the software program Smart PLS 3.0 is used to assess the validity of the hypothesis. Using path coefficients (β) and T-statistics, the evaluation of the inner model assesses the direct correlation among constructs taken into consideration for the study. **Chapter 6** delves into further details about the study and testing of hypotheses.

3.5.7 Model Validation and Recommendations

The distinctive significance of this research to the literature is that it has provided empirical evidence for the conclusion drawn regarding the identification of the effects of I4A, DC, and CEP on SOP. Another unique addition of this study is that it is the first to examine the combined effect of the prominently identified key drivers of I4A, DC, and CEP on I4A, DC, and CEP.

Additionally, the study confirmed the link between I4A and SOP and offered new perspectives on it by investigating the impacts, both direct and indirect of DC and CEP on SOP. This is a significant contribution to the study. To further ensure the integrity and consistency of the research, the findings were also discussed with the experts. The outcome is validated further through the developed mathematical modeling by deriving the equation expressing the relationship among the key constructs. Further, derived study implications and recommendations are discussed in **Chapter 7.**

3.6 Conclusions

An organized research plan and the measures taken to carry out the current research study are outlined at the beginning of the chapter. The study strategy follows the most well-known, highly reliable, and preferred research methodologies used in this research work to accomplish the defined objectives and research queries mentioned earlier in **Chapter 1.** This thesis aims to evaluate an organization's SOP in light of the I4A while examining how the synergistic linkage between DC and CEP influences the connection between I4A and SOP. The chapter elaborates on the journey highlighting the basis of problem formulation to the final model development, validation, and recommendation. An exploratory case study approach is used because of the current research's nature, as the topic considered for the current study is emerging, and there is a dearth of literature to gain a broader understanding of the topic. The strategy for case selection, the number of cases, and the compilation of initial documents are covered in-depth, along with the plan and methodology for conducting case studies from various manufacturing industry sectors and academia in India. The current research is guided by the framework that has been developed. The hypothesis is formulated concerning the objective of the current research based on the analysis of existing literature and case study results. The design and development of a survey questionnaire were described in the current chapter. Since it can explain and quantitatively expose the variability of targeted population traits, survey methodology is applied. The survey instrument's measuring indicators are described concerning its information and measurement scale. The survey results are then evaluated by academicians and industrial sector experts with extensive experience in digitalization, I4.0 projects, intelligent manufacturing, advanced manufacturing technologies, automation, and strategic management. The entire execution of the final survey is detailed in **Chapter 6.** The methodologies used to assess the survey results, the data collection sources, and the characteristics of the target sample are all examined in-depth. Further, the first exploratory case study is explained in full in the next chapter.

4 Key Success Factors Assessment Impacting Industry 4.0 Adoption in the Indian Manufacturing Industry

4.1 Chapter Summarization:

I4.0 has gained popularity in the manufacturing industry due to its perceived benefits, like cost control, improved quality, enhanced productivity, higher performance, and significant returns on investment. Hence it has prompted policymakers and professionals to consider I4A a priority to leverage the competitive advantage. This study empirically examines the main determining factors for deploying I4.0 in an Indian manufacturing organization. The researcher initially retrieved significant Key Success Factors (KSFs) and analyzed them using the most influential determining Key Performance Indicators (KPIs). Furthermore, the prioritized ranking of these KSFs has been performed to build confidence and direct the strategy for the manufacturing companies to implement the I4.0 paradigm successfully. This study has taken advantage of the perspectives of experts in the manufacturing sector to make the study realistic and practically feasible. The significant outcome of the study is the internet network infrastructure and current technological status to comply with I4.0 are the most prominent determining success factors in implementing the I4.0 realm. Study findings confirm that seamless internet connectivity, low latency, and internet infrastructure steadiness should be considered necessary for successful I4.0 implementation. I4.0 managers and professional policymakers could use provided preference order of KSFs to guide their work to develop I4.0 execution road map and a strategic plan. The study recommends that industrial organizations formulate effective policies and strategies to deploy I4.0, further boosting the company's performance.

4.2 Introduction

The fast-paced business environment poses challenges for many industrial organizations to remain competitive. Therefore, intelligent customers, product quality, processes, operations agility, and competitiveness in these business functions are the crucial concerns of an organization that necessitate attention and consideration (Fatorachian and Kazemi, 2018; Frank et al., 2019). The core elements of I4.0 are the

CPS, AR, VR, BDA, CC, AM, IoT, ML, Cybersecurity, Simulation, embedded systems, and many other peripherals. I4.0 is, therefore, a gradual process of planning, implementing, and managing the entire value stream of the product life cycle and should be handled carefully for its effective deployment. I4.0 is linked to the close involvement of people in the production procedures to ensure process amelioration, emphasize extremely crucial activities, and waste elimination. Hence owing to this, it is observed that Indian manufacturing firms face numerous difficulties, including a shortage of knowledge of I4.0, an insufficient infrastructure, inadequate training, and a lack of skills, concerns about cybersecurity and data governance, standards, government engagement, and many more. This is due to the absence of a framework for its smooth implementation. Thus, the KSFs and KPIs of I4.0 must be addressed effectively for I4.0 to be implemented successfully to bring clarity to the front pros and cons of the I4.0 paradigm, as it is at the infant level in current perception (Kamble et al., 2018b; Tupa et al., 2017).

Hence referring to the above concerns, the researcher has tried to frame the research inquiries as mentioned below:

RQ1: What are the most prominent KSFs and KPIs of I4.0?

RQ2: Which I4.0 KSF is the most crucial while ranking based on the I4.0 KPIs using the EDAS method?

RQ3: What are the significance and ramifications of the devised model?

The study's substantial contribution to the literature is emphasized below in regard to the aforementioned research questions.

1. It explores the theoretical foundations for KPIs associated with I4A and the most critical I4.0 KSF, accompanied by their assessment and evaluation using a cautiously chosen MCDM method, which distinguishes the study from others.
2. The research's legitimacy is established by applying SLR, experts' involvement, and expertise in leading I4.0 projects.
3. The meticulously proposed approach will guide manufacturing industry practitioners, consultants, and academicians in suggesting improved methods and approaches to enhance execution performance in the I4.0 setting through prudent I4.0 KPI and KSF management.
4. The study's findings are sufficiently supported and provide reasoning based on past investigations, making it a distinctive addition to new information.

5. Along with the aforementioned, the study's implications and recommendations can serve as a foundation for easing the I4A and assisting manufacturing firms in efficiently managing their capabilities and resources to maximize sustainable development.

The following sections elaborate on 4.3 Literature Review, 4.4 Research Methodology, 4.5 Model Development for Key Success Factors Assessment Impacting I4A in the Indian Manufacturing Industry, 4.6 Results and Analysis, 4.7 Discussions and Study Implications, and 4.7 Conclusion.

4.3 Literature Review

The researcher concurs that the foundation of every quality research study is the SLR, which offers a solid foundation to build a robust research framework. This study considers a comprehensive LR and expert opinion to retrieve the essential manufacturing industry's KSFs and KPIs for I4.0. Further, to evaluate I4.0 KSFs based on the identified KPIs, strong support is received from the existing literature review elaborated ahead in this section, confirming the need for the current study to promote the successful progression of I4.0. The fundamental objective of I4.0 is to integrate technologies such as AI, BDA, IoT, CC, CPS, and AM to create an intelligent facility where CPS is a crucial component, can interact with both people and machines, and can help with environmentally friendly manufacturing procedures (Fakhar Manesh et al., 2021; Piccarozzi et al., 2018; Stentoft and Rajkumar, 2020). As I4.0 technology is introduced, people's working perceptions will change, making businesses more competitive. Although it is a fact, the problem facing the I4A is resistance to change; thus, top management and leadership are crucial in overcoming this, and the challenges listed above cannot be ignored (Lopes de Sousa Jabbour et al., 2018; Moktadir et al., 2018; Young and Jordan, 2008). Thus, the earlier studies show that, the larger spectrum of KSFs for I4A has received very little attention in research. Professional practitioners and leaders have realized that numerous critical success factors for adopting I4.0 technologies must be researched and assessed to realize their benefits (Dassisti et al., 2019; Moeuf et al., 2018). Thus, these issues need urgently be addressed for implementing I4.0 initiatives in Small and Medium Scale Industries (SMEs) in the Indian context. Therefore, to build stakeholders' belief in moving ahead on the path of the I4.0 paradigm change, the researcher noticed that earlier investigations have a dearth of similar study literature on I4.0 KSF and KPI. Also, it has been observed that either assessed the I4.0 KSFs and KPIs in a restricted way or did not assess the KSFs using the clearly stated and crucial KPIs (Kodym et al., 2020; Pandey et al., 2021). This instigates the researcher to confront the critical issue of locating the most significant KSFs by considering the most crucial KPIs and developing the ranking of KSFs by concentrating on their significance with an apt selection of MCDM.

The recent literature shows that the MCDM deployment approach is most frequently utilized to address complex technical and management-oriented issues in practical applications in the I4.0 context (Vaidya et al., 2018). Hence, concerning this, the study used the DEMATEL technique to identify the causal interactions between I4.0 enablers to attain sustainability (Luthra et al., 2020). The factors influencing the service and manufacturing industries' preparation for the I4A were assessed using the PROMETHEE, TOPSIS, ELECTRE, and AHP methodologies. These four methodologies' findings were examined for their efficacy and deficiencies that applied to the concern issue undertaken (Trstenjak et al., 2019). Moraliyska and Antonova (2018) reviewed the most recent advancements in I4A in European countries, considering data gathered by conducting expert interviews with local SMEs in Bulgaria. In line with conducting an in-depth discussion with I4.0 experts, small and medium-sized manufacturers' readiness confirms that using digital infrastructure is a crucial success factor (Harris et al., 2019). A study was conducted by Pirola et al. (2020), utilizing an analytical and several case study methodologies to assess the evolution of I4A in twenty Italian manufacturing organizations. The findings conclude that the managers of Italian manufacturing organizations are eager to develop efficient solutions for implementing I4.0. Sevinç et al. (2018) have explored using AHP and ANP that the organizational, environmental, innovation, and financial factors are crucial for I4A (Bhagawati et al., 2019). DEMATEL was adopted in the research to examine the efficiency and feasibility of supply chain management for the I4A. Moktadir et al. (2018) established the methodology for assessing challenges with the BMW methodology and ranked the challenges. Similar to this, Yadav et al. (2020) devised a hybrid MCDM framework by taking into account BWM and ELECTRE techniques to address issues with building a circular economy-based innovation and supply chain sustainability.

While dealing with conflicting criteria in solving the MCDM problem, the EDAS approach is considered very effective in handling this (Ghorabaee et al., 2015).

Therefore, using the most prevalent MCDM method, i.e., EDAS, for problem-solving in industrial settings renders this research unique and extremely productive because it fills a gap in previous studies by ensuring the robustness and sustainability of the solution. This establishes the validity and relevance of the current research's contribution to new knowledge and provides researchers, decision-makers, and policymakers with a basis upon which to build their strategies for making the best use of the capacities and resources at their disposal to gain a competitive edge and sustainability. Thus, this study selected nine KPIs and eleven KSFs for analysis based on the intervention of SLR and I4.0 domain experts. The identified KSFs were evaluated using these KPIs. The conclusions of this research will undoubtedly be used to expand the existing knowledge base and aid managers and professional practitioners in developing an implementation strategy for I4.0. **Table 4.1** and **Table 4.2** contain a list of the KSFs and KPIs incorporated into this study.

Table 4.1: Key Success Factors for Adoption of Industry 4.0

S N	Key Success Factors	Brief description	Literature support
1	Management support and leadership (KSF1)	Effective enterprise resources and capabilities management necessitates a diligent leadership attitude and top management dedication in aligning the organization's goals of deploying emerging technology innovations.	Nair et al., (2019);Stentoft et al. (2021)
2	Internet network infrastructure (KSF2)	It consists of the extraneous components that support the internet network infrastructure, such as data storage, workstations, servers, data execution hardware/software, low latency networks, efficient data transfer, and effective intercommunication interfaces.	Stock et al. (2018)

S N	Key Success Factors	Brief description	Literature support
3	Financial assistance (KSF3)	It involves the deployment of adequate financial assistance, which refers to the distribution of funds for services and operations, as well as resource management to keep up with new technological breakthroughs in the organization.	Nair et al. (2019); Widayani et al. (2020)
4	Data security (KSF4)	It alludes to a dearth of trust in contemporary technology, unsafe data processing and execution, concerns about its ability, and reservations about its possible detrimental repercussions.	Rajnai and Kocsis (2017); Widayani et al. (2020)
5	Team coordination and collaboration (KSF5)	Effective communication, information sharing, and teamwork among all key participants in the value chain are crucial issues. The team's coordination and collaboration are essential to achieving an organization's sustainability goal, as is the delegation of powers and responsibilities.	Luthra et al. (2020)
6	Current workforce competency compliant with I4.0 needs (KSF6)	It is expected that current employees to become compliant with the necessary prerequisite technological know-how needed for new technology infrastructure and evolving business model advancement requirements.	Moraliyska and Antonova (2018)

S N	Key Success Factors	Brief description	Literature support
7	Competitive pressure from the business Partners (KSF7)	This comprises competitive pressure from business partners and competitors, pushing organizations to implement innovative technology.	Sriram and Vinodh (2020)
8	Accessibility and interoperability of hardware and software (KSF8)	The distribution of data and information inside an organization is significantly influenced by the high quality, compatibility, and accessibility of technology, software, and hardware.	Safar et al. (2018)
9	Legal and government support (KSF9)	Governmental infrastructure support, legislative laws, and regulations are projected to aid in overcoming the challenges companies must overcome to roll out I4.0.	Bag et al. (2021)
10	Expectations of the customer (KSF10)	Companies must maintain a strong emphasis on customer expectations to maintain productive relationships with customers without compromising the quality of service or productivity.	Mittal et al. (2018)
11	Current technological status to comply with I4.0 (KSF11)	It is expected that the existing technical infrastructure must be upgraded to make progress toward the I4.0 vision. In this light, the sensors and actuators, IoT devices, and information technology infrastructure fitted with embedded systems will substantially contribute to rendering existing technology compatible with I4.0.	Lu (2017)

Table 4.2: Key Performance Indicators for Adoption of Industry 4.0

S N	Key Performance Indicators	Brief description	Literature support
1	Virtualization (KPI1)	This makes smooth interactions possible between companies and provides all participating organizations access to pertinent product and production statistics in real-time to benefit everyone involved in the interface.	Siltori et al.(2021)
2	Connectivity (KPI2)	It refers to the interconnection capabilities and amounts of data transferred across all platforms, services, and networks.	Müller et al. (2018)
3	Interoperability (KPI3)	It is a term used to describe the capacity of various computer systems and devices to share information, use the capabilities offered, and work collaboratively.	Lu (2017); Saturno et al. (2017)
4	Service orientation (KPI4)	This refers to the facilities' orientation suited to the needs of the customer, people, and smart objects or gadgets to communicate effectively through the Internet of Services.	Kozak et al. (2018); Raj et al. (2019)
5	IT. Infrastructure (KPI5)	The physical infrastructure's capabilities and resources are needed to store and comprehend the massive amounts of data constantly streaming through the system and turn them into insightful information by working with everyone throughout the value chain.	Wiesner et al. (2018)

S N	Key Performance Indicators	Brief description	Literature support
6	Real-time decision-making capabilities (KPI6)	The intelligence of an industry can gather information, retain, examine, and process it, and then derive significant insights from the compiled data that can be utilized to make decisions in real-time.	Lu and Ju (2017); Lee et al. (2017)
7	Modularity (KPI7)	It streamlines the devices while simultaneously producing building blocks that can be used multiple times, providing flexibility in terms of manufacturing capacity and product preference.	Saturno et al. (2017);Trstenjak et al. (2019)
8	Collaboration potential between connected devices (KPI8)	It refers to the capacity of interconnected devices to self-measure, become aware of, and predict potential consequences.	Stentoft et al. (2021)
9	Decentralization (KPI9)	The system can perform all decisions independently with minimal human interaction, enabling the transmitted delegation of powers and responsibilities, facilities, and CPS through handling autonomously.	Moktadir et al. (2018)

4.4 Research Methodology

This study intends to order the I4.0 KSFs according to the most important I4.0 KPIs derived through SLR and six expert responses and engagement from six manufacturing companies in Maharashtra, India. The researcher has been given precise inputs from industry professionals, which boosted the confidence to reach realistic solutions for the problem undertaken for the study. The experts are selected after evaluating their credentials, competency, expertise, and experience in executing the I4.0 project on their credit. The hierarchical decision-making structure used in this research to evaluate prospective KSFs using the most significant I4.0 KPIs is depicted in **Figure 4.1; Sections 4.1 and 4.2** include descriptions of the comprehensive expert profile, data collection, and data validation taken into account in this study. Before framing the research questions, the researcher assessed the significant SLR support and espoused its importance to the ongoing investigation as the MCDM employs the EDAS approach to prioritize I4.0 KSFs. The choice of suitable MCDM approaches for the current study demonstrates the reliability of the outcomes because it is confirmed adopting the SLR that the EDAS precisely addressed to rank the alternatives incorporating conflicting criteria. **Figure 4.2** shows the systematic approach followed in the research methodology elaboration for the current study.

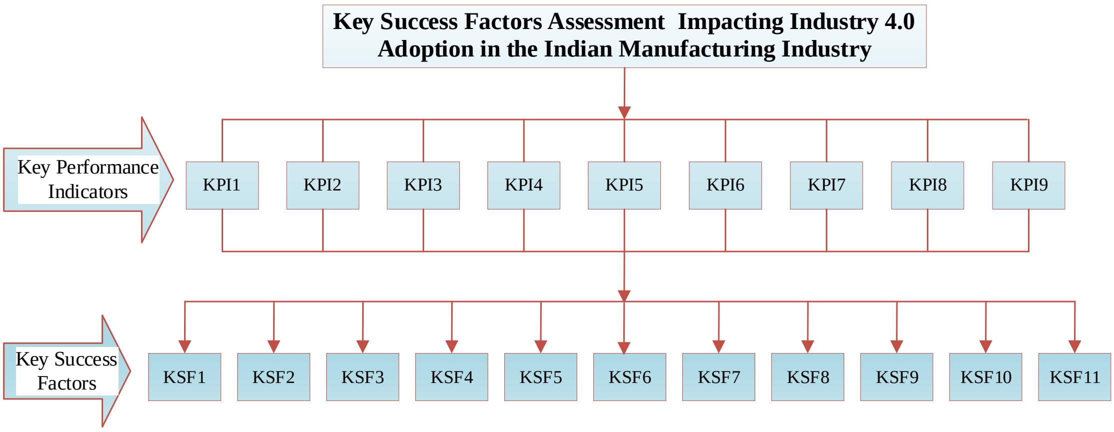

Figure 4.1: Hierarchical Structure for Industry 4.0 Key Success Factors Prioritization

Note:

I4.0 KPIs:-KPI1: Virtualization, KPI2: Connectivity, KPI 3: Interoperability, KPI4: Service orientation, KPI 5: IT. Infrastructure, KPI6: Real-time decision-making capabilities, KPI7: Modularity, KPI8: Collaboration potential between connected devices, KPI9: Decentralization.

I4.0 KSFs:- KSF1: Management support and leadership, KSF2: Internet network infrastructure, KSF3: Financial assistance, KSF4: Data security, KSF5: Team coordination and collaboration, KSF6: Current workforce competency compliant with I4.0 needs KSF7: Competitive pressure from the business Partners, KSF8: Accessibility and interoperability of hardware and software, KSF9: Legal and government support, KSF10: Expectations of the customer, KSF11: Current technological status to comply with I4.0.

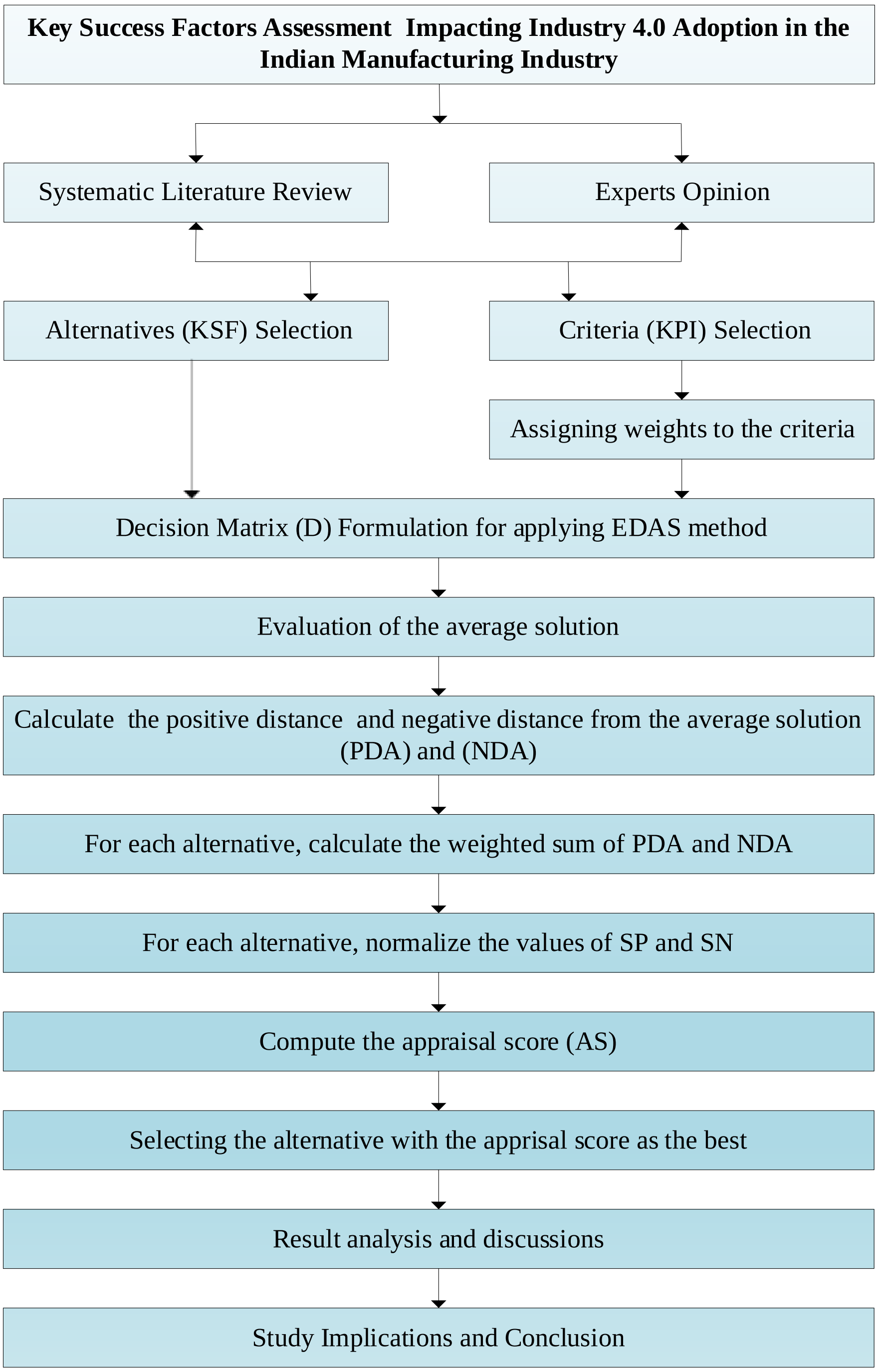

Figure 4.2: The Schematic Presentation of the Research Methodology followed in the Current Study

4.4.1 Alternatives Evaluation Methodology based on Distance from Average Solution (EDAS)

The optimal alternative is chosen using the EDAS method by measuring the distance of each alternative from the ideal value, which is especially useful in situations with contradicting attributes. This method was developed by Ghorabaee et al.(2015) and used to address the inventory categorization problem for the first time. Some of the highlights of the EDAS methods which makes it popular are listed below:

- Simplicity: EDAS is relatively straightforward to understand and implement compared to other MCDM methods.
- Efficiency: EDAS can be computationally efficient, making it suitable for situations with a large number of alternatives or criteria.
- Flexibility: EDAS can handle both maximization and minimization objectives, making it versatile for a wide range of decision-making scenarios.
- Decision-Maker Preferences: EDAS takes into account the preferences of decision-makers by evaluating each alternative's distance from the ideal solution.
- Applicability: EDAS has been successfully applied in various Engineering and management applications.
- Availability of Software: The availability of software tools or packages that support the implementation of EDAS can make it more accessible and easier to use.

The methodological steps followed in EDAS are explained as follows.

Step 1: Identify the most important criteria and alternatives to identify the most crucial alternative based on the criteria considered.

Step 2: Create the Decision Matrix (D) according to the matrix formulation indicated below.

$$D = \left[D_{ij}\right]_{nxm} = \begin{bmatrix} d_{11} & d_{12} & \dots & d_{1m} \\ d_{21} & d_{22} & \dots & d_{2m} \\ d_{31} & d_{32} & \dots & d_{3m} \\ \dots & \dots & \dots & \dots \\ d_{n1} & d_{n2} & \dots & d_{nm} \end{bmatrix} \text{------------} \quad (1)$$

Here D_{ij} signifies the performance measure of the ith alternative depends on the jth criteria.

Step 3: Examine the average solution on the basis of using all of the criteria, as shown below

$AV = [AV_j]_{1xm}$ ------------ (2) Here, $AV_j = \frac{\sum_{i=1}^{n} D_{ij}}{n}$ ------------ (3)

Step 4: Depending on the criterion, which may be beneficial or not, determine the positive distance from the average solution (PDA) and the negative distance from the average solution (NDA).

$PDA = [PDA_{ij}]_{nxm}$ ------------ (4) $NDA = [NDA_{ij}]_{nxm}$ ------------ (5)

Considering j^{th} criteria as beneficial criteria

$PDA_{ij} = \frac{\max(0,(D_{ij} - AV_j))}{AV_j}$ ------------ (6) $NDA_{ij} = \frac{\max(0,(AV_j - D_{ij}))}{AV_j}$ ------------ (7)

Considering j^{th} criteria as non-beneficial criteria

$PDA_{ij} = \frac{\max(0,(AV_j - D_{ij}))}{AV_j}$ ------------ (8) $NDA_{ij} = \frac{\max(0,(D_{ij} - AV_j))}{AV_j}$ ------------ (9)

Whereas, PDA_{ij} denotes the positive distance from the average solution in the context of the i^{th} alternative and the j^{th} criterion and NDA_{ij} denotes the negative distance from the average solution.

Step 5: The weighted sum of the PDA and NDA should be calculated for each alternative decision using the formula presented below.

$SP_i = \sum_{j=1}^{m} w_j PDA_{ij}$ ------------ (10) $SN_i = \sum_{j=1}^{m} w_j NDA_{ij}$ ------------ (11)

Here, w_j is the weight of j^{th} criteria

Step 6: Applying the following equation to each alternative to normalize their SP and SN values.

$NSP_i = \frac{SP_i}{max_i(SP_i)}$ ------------ (12) $NSN_i = 1 - \frac{SN_i}{max_i(SN_i)}$ ------------ (13)

Step 7: Determine the Appraisal score (AS) for each available alternative using the formulas below.

$AS_i = \frac{1}{2}(NSP_i + NSN_i)$ ------------ (14) Here, $0 \leq AS_i \leq 1$

Step 8: The best alternative was determined to be the one with the greatest appraisal score.

4.5 Model Development for Key Success Factors Assessment Impacting Industry 4.0 Adoption in the Indian Manufacturing Industry

The applicability of the designed research framework is detailed in this section. As evidenced by earlier studies, the MCDM problem's outcomes have always been facilitated by practitioners' expertise pertaining to the I4.0 sphere (Moktadir et al., 2018). Thus, the experts for the current study have been carefully selected, as noted in **Table 4.3** taking into account their understanding and competence to address the current research objective. Six experts from the six manufacturing organizations are deemed suitable and reliable for the analysis. Nine important KPIs and eleven prominent KSFs were confirmed after the elevated discussions and in-depth SLR to create a thorough and reliable model, as shown in **Table 4.1 and Table 4.2.**

4.5.1 Profile of the Experts Involved in this Study

This study ascertained that each expert selected for the current analysis represents the leading manufacturing firms in India's public and private spheres. These organizations are some of the few in the sector that sought to integrate I4.0 technology into their operational processes to maintain their competitiveness in national and international markets. Their endeavors included adding sensors, IIoT equipment, and network infrastructure and developing skills for the current workforce in their current organizational settings, which led to surveillance, risk evaluation, real-time machine condition monitoring, and decision-making. The essential part of these initiatives is workforce upgradation through training and facilitation of acquiring cutting-edge operational techniques via emerging technology. Blockchain, IoT, IIoT, robotics and cobots, 3D printing, CC, ML, AI, VR and AR, and CPS are a few of these, which enable companies to meet client demand more swiftly than in the past. The information on the professional's profile considered for the study is mentioned in **Table 4.3.**

Table 4.3: Characteristics of the Study's Focused Group Profile

Experts origin	Type of Company	Position in the Company	Expertise Domain	Qualification	Job Experience
Experts From Industry	Automobile	Departmental Head	Digital technologies, supply chain, and production and operations management.	Master in Mechanical Engineering	22 years
	Ammunition hardware manufacturing,	General Manager	Operations and processes management, digital technologies.	Master in Industrial Engineering	16 years
	Furniture manufacturing,	Owner and CEO	Supply chain, digital technologies, and production and operations management,	Ph.D. in Production Engineering	24 years
	Plastic industry,	Senior Manager	I4.0 projects, lean and green management, manufacturing operations	Master in Plastic Technology	20 years
	Energy sector	Senior Manager	I4.0 projects, sales, and digital marketing,	Master in Electrical Engineering	16 years
	IT and software	Departmental Head	Software and hardware solutions, I4.0	Master in Computer Science	18 years

Experts origin	Type of Company	Position in the Company	Expertise Domain	Qualification	Job Experience
			projects, cyber security,		

4.5.2 Data Collection Process and Validation

The expected growth of I4A is still being impeded by unaddressed issues, including the absence of I4.0 KSFs and KPIs identification and evaluation framework, despite the manufacturing industries' proactive I4A goal through persistent innovations, experimenting, and development. As a result, policymakers, researchers, and technical experts devoted urgent attention to the I4.0 KSFs assessment and evaluation. The selection of experts from a diverse range of industry disciplines attempting to solve the pervasive ambiguity around I4A in industries ensures the true image of I4A in Indian manufacturing firms. Therefore initially, the identified alternatives (KSFs) and criteria (KPIs) for the study were provided with detailed descriptions to all the experts to offer detailed comprehension of each KSF and KPI. Further, to receive the KSF and KPI interrelationship data, this exercise provides each expert with a blank matrix that reflects the relationship effectiveness between the KSFs and KPIs i.e., the i^{th} KSF's effectiveness on the j^{th} KPI. This undoubtedly made it easier for the experts to comprehend the issue and accurately fill out the matrix using their I4.0 experience. For the purpose of performing the EDAS, each expert was asked to complete the matrix according to the linguistic scale provided for designating the relationship (Sriram and Vinodh, 2020), as indicated in **Table 4.4.** This information was gathered from the experts at their convenience using Google Form, phone conversations, emails, and in-person meetings.

Further, for the collected data validation, the six other researchers and I4.0 domain experts from industry and academia who were not involved in the data collection procedure mentioned earlier were invited to discuss the obtained inputs to ensure the study outcomes. These individuals had a combined professional experience of more than 20 years and had experience in I4.0 endeavors. They also successfully carry out research in the I4.0 field, operations and process management, and supply chain. They assisted in validating and testing the established framework. This data validation technique was used to eliminate biases and inaccuracies from the data collection and guarantee the results' accuracy and coherence from an external assessment standpoint (Yin, 2009).

4.5.3 Application of EDAS Method

In line with the steps outlined in **Section 4.4.1**, the EDAS approach ranks the selected eleven KSFs based on nine KPIs. The experts requested that they assign weights to the criteria and score the relationship between the alternatives and the criteria according to the linguistic scale provided in **Table 4.4 (Step 1).**

Once the KPIs were identified, Experts intervention was sought on the appropriateness of the KPI's in the given context. Further, all the Experts were requested to allot the weights on the scale provided in **Table 4.4.**

Final weights were allotted to each of the KPIs by applying the criteria of maximum acceptability and agreeableness. According to the experts' subjective judgments, the following weights were offered to the KPIs.

KPI1: Virtualization (0.05), KPI2: Connectivity (0.15), KPI 3: Interoperability (0.15), KPI4: Service orientation (0.1), KPI 5: IT. Infrastructure (0.15), KPI6: Real-time decision-making capabilities (0.15), KPI7: Modularity (0.05), KPI8: Collaboration potential between connected devices (0.1), KPI9: Decentralization (0.1).

The experts' linguistically scaled input is first used to build the decision matrix, which is then converted depending on the corresponding rating. Each criterion's average solution is determined and presented in **Table 4.5 and Table 4.6 (Steps 2 and 3).**

Furthermore, **Table 4.7 and Table 4.8** beneficial and non-beneficial criteria are converted into the positive distance from average (PDA) and negative distance from average (NDA) values **(Step 4).** The only unfavorable criterion is the IT Infrastructure (KPI5), while all other criteria are beneficial. As a result, the IT infrastructure with a lower value is more desirable, and the higher values for all the other criteria were better. **Table 4.9** and **Table 4.10 (Step 5)** show the weighted sum of PDA and NDA obtained. Following **Table 4.11** are the normalized values of SP, SN, and Appraisal Score (AS) for all alternatives **(Steps 6 and 7).** The ranking column in **Table 4.11** demonstrates that the option with the highest AS is seen as being the best alternative. Thus **Table 4.11** shows that alternative internet network infrastructure (KSF2) should be prioritized for I4A as it has the highest AS value of all the alternatives, i.e., 0.9959, which has the highest AS value among all the others.

Table 4.4: Linguistic Scale Utilized for Expert Input.

Interpretation	Code	Score
Extremely Effective	EE	1
Highly Effective	HE	0.9
Very Effective	VE	0.8
Moderately Effective	ME	0.7
Fairly Effective	FE	0.6
Slightly Less Effective	SLE	0.5
Moderately Less Effective	MLE	0.4
Very Less Effective	VLE	0.3
Highly Less Effective	HLE	0.2
Extremely Less Effective	ELE	0.1

Table 4.5: Initial Input Decision Matrix

KSF/KPI	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9
KSF1	ME	ME	ME	ME	ME	ME	SLE	ME	VE
KSF2	ME	HE	VE	VE	VE	VE	ME	VE	EE
KSF3	VE	ME	SLE	ME	HE	VE	ME	VE	SLE
KSF4	VE	HE	VE	VE	HE	ME	ME	ME	EE
KSF5	ME	ME	FE	ME	VE	VE	VE	VE	VE
KSF6	SLE	FE	ME	ME	VE	ME	ME	ME	ME
KSF7	FE	SLE	ME	ME	ME	FE	SLE	FE	FE
KSF8	VE	HE	VE	ME	VE	ME	VE	VE	ME
KSF9	FE	ME	VE	VE	HE	VE	ME	VE	ME
KSF10	HE	VE	VE	VE	VE	ME	ME	VE	VE
KSF11	VE	VE	HE	VE	VE	ME	ME	VE	HE

Table 4.6: Converted Decision Matrix based on Numeric Score

KSF/KPI	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9
KSF1	0.70	0.70	0.70	0.70	0.70	0.70	0.50	0.70	0.80
KSF2	0.70	0.90	0.80	0.80	0.80	0.80	0.70	0.80	1.00
KSF3	0.80	0.70	0.50	0.70	0.90	0.80	0.70	0.80	0.50
KSF4	0.80	0.90	0.80	0.80	0.90	0.70	0.70	0.70	1.00
KSF5	0.70	0.70	0.60	0.70	0.80	0.80	0.80	0.80	0.80

KSF/KPI	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9
KSF6	0.50	0.60	0.70	0.70	0.80	0.70	0.70	0.70	0.70
KSF7	0.60	0.50	0.70	0.70	0.70	0.60	0.50	0.60	0.60
KSF8	0.80	0.90	0.80	0.70	0.80	0.70	0.80	0.80	0.70
KSF9	0.60	0.70	0.80	0.80	0.90	0.80	0.70	0.80	0.70
KSF10	0.90	0.80	0.80	0.80	0.80	0.70	0.70	0.80	0.80
KSF11	0.80	0.80	0.90	0.80	0.80	0.70	0.70	0.80	0.90
AV_j	0.7181	0.7454	0.7363	0.7454	0.8090	0.7272	0.6818	0.7545	0.7727

Table 4.7: Positive Distance from Average (PDA)

Weights	**0.05**	**0.15**	**0.15**	**0.1**	**0.15**	**0.15**	**0.05**	**0.1**	**0.1**
KSF/KPI	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9
KSF1	0.0000	0.0000	0.0000	0.0000	0.1348	0.0000	0.0000	0.0000	0.0353
KSF2	0.0000	0.2073	0.0864	0.0732	0.0112	0.1000	0.0267	0.0602	0.2941
KSF3	0.1139	0.0000	0.0000	0.0000	0.0000	0.1000	0.0267	0.0602	0.0000
KSF4	0.1139	0.2073	0.0864	0.0732	0.0000	0.0000	0.0267	0.0000	0.2941
KSF5	0.0000	0.0000	0.0000	0.0000	0.0112	0.1000	0.1733	0.0602	0.0353
KSF6	0.0000	0.0000	0.0000	0.0000	0.0112	0.0000	0.0267	0.0000	0.0000
KSF7	0.0000	0.0000	0.0000	0.0000	0.1348	0.0000	0.0000	0.0000	0.0000
KSF8	0.1139	0.2073	0.0864	0.0000	0.0112	0.0000	0.1733	0.0602	0.0000
KSF9	0.0000	0.0000	0.0864	0.0732	0.0000	0.1000	0.0267	0.0602	0.0000
KSF10	0.2532	0.0732	0.0864	0.0732	0.0112	0.0000	0.0267	0.0602	0.0353
KSF11	0.1139	0.0732	0.2222	0.0732	0.0112	0.0000	0.0267	0.0602	0.1647

Table 4.8: Negative Distance from Average (NDA)

Weights	**0.05**	**0.15**	**0.15**	**0.1**	**0.15**	**0.15**	**0.05**	**0.1**	**0.1**
KSF/KPI	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9
KSF1	0.0253	0.0610	0.0494	0.0610	0.0000	0.0375	0.2667	0.0723	0.0000
KSF2	0.0253	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
KSF3	0.0000	0.0610	0.3210	0.0610	0.1124	0.0000	0.0000	0.0000	0.3529
KSF4	0.0000	0.0000	0.0000	0.0000	0.1124	0.0375	0.0000	0.0723	0.0000
KSF5	0.0253	0.0610	0.1852	0.0610	0.0000	0.0000	0.0000	0.0000	0.0000

Weights	0.05	0.15	0.15	0.1	0.15	0.15	0.05	0.1	0.1
KSF6	0.3038	0.1951	0.0494	0.0610	0.0000	0.0375	0.0000	0.0723	0.0941
KSF7	0.1646	0.3293	0.0494	0.0610	0.0000	0.1750	0.2667	0.2048	0.2235
KSF8	0.0000	0.0000	0.0000	0.0610	0.0000	0.0375	0.0000	0.0000	0.0941
KSF9	0.1646	0.0610	0.0000	0.0000	0.1124	0.0000	0.0000	0.0000	0.0941
KSF10	0.0000	0.0000	0.0000	0.0000	0.0000	0.0375	0.0000	0.0000	0.0000
KSF11	0.0000	0.0000	0.0000	0.0000	0.0000	0.0375	0.0000	0.0000	0.0000

Table 4.9: Weighted Sum of PDA

KSF/ KPI	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9	KSF/ KPI
KSF1	0.0000	0.0000	0.0000	0.0000	0.0202	0.0000	0.0000	0.0000	0.0035	0.0238
KSF2	0.0000	0.0311	0.0130	0.0073	0.0017	0.0150	0.0013	0.0060	0.0294	0.1048
KSF3	0.0057	0.0000	0.0000	0.0000	0.0000	0.0150	0.0013	0.0060	0.0000	0.0281
KSF4	0.0057	0.0311	0.0130	0.0073	0.0000	0.0000	0.0013	0.0000	0.0294	0.0878
KSF5	0.0000	0.0000	0.0000	0.0000	0.0017	0.0150	0.0087	0.0060	0.0035	0.0349
KSF6	0.0000	0.0000	0.0000	0.0000	0.0017	0.0000	0.0013	0.0000	0.0000	0.0030
KSF7	0.0000	0.0000	0.0000	0.0000	0.0202	0.0000	0.0000	0.0000	0.0000	0.0202
KSF8	0.0057	0.0311	0.0130	0.0000	0.0017	0.0000	0.0087	0.0060	0.0000	0.0661
KSF9	0.0000	0.0000	0.0130	0.0073	0.0000	0.0150	0.0013	0.0060	0.0000	0.0426
KSF10	0.0127	0.0110	0.0130	0.0073	0.0017	0.0000	0.0013	0.0060	0.0035	0.0565
KSF11	0.0057	0.0110	0.0333	0.0073	0.0017	0.0000	0.0013	0.0060	0.0165	0.0828

Table 4.10: Weighted Sum of NDA

KSF/KPI	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9
KSF1	0.0013	0.0091	0.0074	0.0061	0.0000	0.0056	0.0133	0.0072	0.0000
KSF2	0.0013	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
KSF3	0.0000	0.0091	0.0481	0.0061	0.0169	0.0000	0.0000	0.0000	0.0353
KSF4	0.0000	0.0000	0.0000	0.0000	0.0169	0.0056	0.0000	0.0072	0.0000
KSF5	0.0013	0.0091	0.0278	0.0061	0.0000	0.0000	0.0000	0.0000	0.0000
KSF6	0.0152	0.0293	0.0074	0.0061	0.0000	0.0056	0.0000	0.0072	0.0094
KSF7	0.0082	0.0494	0.0074	0.0061	0.0000	0.0263	0.0133	0.0205	0.0224

KSF/KPI	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9
KSF8	0.0000	0.0000	0.0000	0.0061	0.0000	0.0056	0.0000	0.0000	0.0094
KSF9	0.0082	0.0091	0.0000	0.0000	0.0169	0.0000	0.0000	0.0000	0.0094
KSF10	0.0000	0.0000	0.0000	0.0000	0.0000	0.0056	0.0000	0.0000	0.0000
KSF11	0.0000	0.0000	0.0000	0.0000	0.0000	0.0056	0.0000	0.0000	0.0000

Table 4.11: Ranking of the Alternatives.

KSF	SPi	SNi	NSPi	NSNi	ASi	Rank
KSF1	0.0238	0.0501	0.2266	0.6737	0.4501	8
KSF2	0.1048	0.0013	1.0000	0.9918	0.9959	1
KSF3	0.0281	0.1155	0.2676	0.2475	0.2576	9
KSF4	0.0878	0.0297	0.8377	0.8065	0.8221	3
KSF5	0.0349	0.0443	0.3330	0.7116	0.5223	7
KSF6	0.0030	0.0802	0.0288	0.4775	0.2531	10
KSF7	0.0202	0.1535	0.1929	0.0000	0.0965	11
KSF8	0.0661	0.0211	0.6308	0.8624	0.7466	5
KSF9	0.0426	0.0436	0.4067	0.7158	0.5612	6
KSF10	0.0565	0.0056	0.5388	0.9634	0.7511	4
KSF11	0.0828	0.0056	0.7902	0.9634	0.8768	2

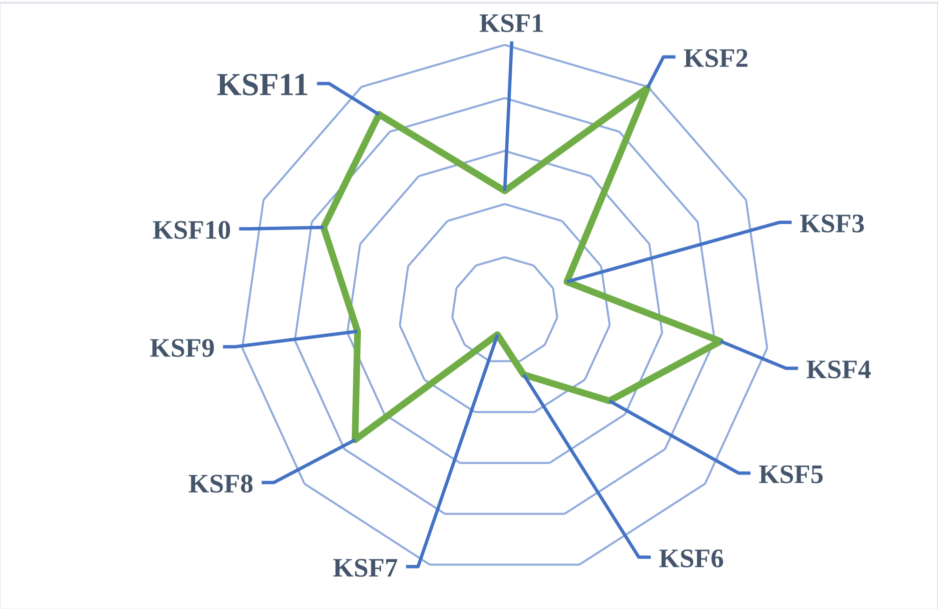

Figure 4.3: Industry 4.0 Key Success Factors Ranking

4.6 Results and Discussions

After analyzing the essential I4.0 KSFs and KPIs, this research aims to rank the derived KSFs in accordance with the important I4.0 KPIs. The study results ensure that it will certainly open up opportunities for the I4A paradigm shift that offers Indian manufacturing industries a sustainable competitive edge. **Table 4.11** and **Figure 4.3** summarize the critical findings of the study obtained from the I4.0 KSFs assessment using EDAS. It is noted from **Table 4.11** that the priority order of the KSFs for I4A in the manufacturing industry derived using the EDAS method is KSF7 < KSF6 < KSF3 < KSF1 < KSF5 < KSF9 < KSF8 < KSF10 < KSF4 < KSF11 < KSF2. It is observed that the KSF2: Internet network infrastructure is the precondition for I4A to realize the mission of smart factories, according to the obtained priority order, because real-time decision-making is made possible by all the components—people, machines, and devices—interacting with one another and sharing data. This is feasible only by implementing an internet network infrastructure with high bandwidth, low latency, and robustness. This finding of the study, followed by second-rank outcome KSF11: Current technological status to comply with I4.0, is strongly supported. Every organization always looks forward to revamping current technical resources before establishing or purchasing new technological infrastructure. Implementing I4.0 becomes more straightforward and practical for organizations if the existing technological resources can be upgraded or modified to comply with I4.0 requirements. In a similar manner, the data security (KSF4), expectations of the customer (KSF10), accessibility and interoperability of hardware and software (KSF8) together with legal and government support (KSF9), team coordination and collaboration (KSF5), management support and leadership (KSF1), financial assistance (KSF3), current workforce competency compliant with I4.0 needs (KSF6), these all are significantly important and require attention as per the preference they have been obtained. According to the study outcome, competitive pressure from the business partners (KSF7) is minimal pertinent than from other KSFs. If the preceding KSFs are appropriately administered, then KSF7 will automatically adjust and can be managed effectively.

4.7 Study Implications

The main goal of this study is to assess the significance of I4.0 KPIs and rank I4.0 KSFs in order to streamline I4A in the manufacturing industries of India. The study outcome indicates that the internet network infrastructure is the most crucial KSF among the eleven KSFs, followed by addressing the one more significant KSF, i.e., the current technological status to comply with I4.0 selected and evaluated using EDAS. This is the extended contribution of this study endorsing the findings of (Luthra et al., 2020). This indicates that seamless accessibility and fast internet broadband network infrastructure are crucial for the effective performance of I4.0 practices. Another prerequisite for monitoring the shop floor production operation is a compatible internet connection between machines, equipment, clouds, and servers. According to Ivanov et al. (2021), an organization adhering to I4.0 must have effective machine-machine and man-machine communication to perform effectively. Also, the robust industrial internet can be installed and integrated with devices and machines to allow product interaction and machine communication. Similarly, CPS encourages the initiative for collaborative efforts between human and machine products (Babiceanu and Seker, 2016; Harris et al., 2019). Therefore, a collaborative amalgamation equipped with internet infrastructure and digital connectivity is essential for efficient human resource management, capability, and competence dissemination across the entire company value chain, agreed to the study findings by (Cimini et al. (2021). This would only be feasible if specialized compatible planning and execution systems use for distinct operational processes and industrial facilities.

Consequently, by incorporating IoT, IIoT, and CC into big data analytics and encouraging upgrades to the existing technological infrastructure by revamping the organization, maintenance capabilities can be ensured after the robust internet network infrastructure and connectivity concerns, if effectively handled. The whole system is more productive and agile when the system is well-maintained and updated. Additionally, reconfiguration and adaptation of I4A techniques in the production system will make it easier to implement. This will further improve the manufacturing process’s excellence, reinforcing the research outcomes (Morgan et al., 2021).

4.7.1 Theoretical Implications

Organizations are still hesitant to embrace I4.0 due to concerns about the unclear details underlying I4.0 KSFs and KPIs and the ambiguous estimated projected returns. The background studies for the accelerated development in the I4.0 epoch are mainly missing from the corpus of extant research. A critical addition to this study is the thoughtful selection of the MCDM technique and verification tools appropriate for the created KSF evaluation framework. Thus, the findings, therefore, have significant theoretical implications. Nine KPIs encompassing all potential KSF assessment characteristics are used to critically evaluate the eleven most essential KSFs. The model developed, as a result, has the potential to direct and assist the decision-makers and researchers involved in the implementation of I4.0. In order to reveal more aspects of I4.0 KSFs and KPIs management and apply the findings of this study to the new paradigm, researchers are encouraged to use this study as a starting point. Thus, developing a strategic plan of action for addressing the most significant KSFs according to their significance while beginning I4.0 implementation will be helpful to swiftly and easily assimilate the internal dynamics of KSFs. The best investigation of this study would serve as a ready reference for researchers and the body of existing literature in this regard. By managing I4.0 KPIs and KSFs wisely, the research can serve as the foundation for an innovative research model and framework for the upcoming research that will guide research scholars for better ways to achieve better proficiency in the I4.0 setting. The study's results support the findings of earlier research and provide substantial justifications, which is its ground-breaking contribution to new knowledge and demonstrates the sturdiness of the proposed model.

4.7.2 Practical Implications

This study has provided some outstanding recommendations for policymakers, leaders, company executives, and practitioners. The insightful conclusions from this study's systematic and analytical approach for the I4.0 KSFs and KPIs assessment will be useful in decision-making. The study has also explored the important link between KPIs and KSFs, which may be particularly relevant to managers, policymakers, experts, and other stakeholders who are part of I4.0 initiatives. This study's findings also point to the need for practitioners to improve their technical expertise and understanding of I4.0 KSFs by building an advanced internet network infrastructure that includes internal and external interconnected network facilities. Therefore, it is important to meticulously examine modern technologies' adaptability and suitability for I4.0's requirements before making decisions about budget planning for possible investments. Managers should understand the organization's needs and available resources to develop a comprehensive and feasible strategy for I4A. Organizations aiming to implement I4.0 should focus on the readiness of employees, team leaders, managers, and policymakers to develop successful action plans for data security measures, collaboration, consumer expectations, and teamwork. Legal and government support are essential, and the government should offer laws, sustainable standards, and regulations to build confidence amongst stakeholders and push tenaciously forward with implementing I4.0. This research is distinctive and makes an all-encompassing effort to provide a model to guide stakeholders as they go incrementally along the I4.0 path.

4.8 Conclusion

With the aid of the EDAS technique, the study has created a model to order the most important KSFs in the realization of I4.0. Eleven KSFs and nine KPIs for the study were finalized and validated using a comprehensive analysis of the literature and the expertise of six industry professionals from six manufacturing sectors in Maharashtra, India. The research findings indicated that the internet network infrastructure is the most critical KSF of the decision-making process for implementing I4.0. It requires more attention because it has attained the top position in findings. By creating a model for KSFs assessment for a viable I4.0 implementation, in various aspects, this study adds worth to the body of literature. In addition to providing a unique perspective, the study will also assist managers, academics, researchers, and policymakers develop implementation timelines for I4.0. All industries planning to adopt I4.0 recently can use the findings to guide how they should structure their plans and strategies for I4.0 KSFs and KPIs.

This study has certain limitations as well. This research has been done to broaden the perspective of I4.0 against the backdrop of Indian manufacturing industries. Consequently, to learn more about I4.0, the same study may be conducted for other countries and industries. Here, nine KPIs and eleven KSFs were chosen for the study. Further investigation into adding more KSFs and KPIs would reveal additional I4.0 dimensions. The KSFs were ranked using the EDAS methodology. Hence to validate the results obtained, various MCDM procedures can be applied. Since expert judgments are the focus of the analysis and expert opinions can vary from person to person, the experts' prejudices may impact the study's findings.

5 Development of an Integrated Framework for Risk Assessment for Industry 4.0 Implementation in the Manufacturing Industry

5.1 Chapter Summarization

Manufacturing industries are looking forward to implementing I4.0 due to its incredible potential advantages, which could impact business model ramifications worldwide. However, because of the scarcity of clarity needed to assess and evaluate its anticipated risks systematically, I4A continues to pose significant complexities. As a response, this study is an attempt to deal with this issue. It intends to facilitate a way forward for manufacturers and policymakers toward the I4.0 paradigm by developing a long-term integrated model to examine and assess important I4.0 KPIs and risks. The study focuses on the five primary risks and ten crucial KPIs identified after a comprehensive literature analysis and twelve professional's interventions. First, the DEMATEL method delineated the causal relationships between the KPIs. Then the CRITIC method is used to calculate the objective weights of each KPI that has been chosen. Further, the MABAC, PROMEETHEE II, MOORA, and COPRAS methods are used to rank the most critical risks among all those that were taken into account for the study. Spearman's correlation coefficient further tested the comparative analysis of the ranking performance obtained from these methods. Finally, a sensitivity analysis is carried out to ensure that the model is accurate and resilient. According to the investigation, information security and cost are the most significant prominence and receiver KPIs. Additionally, in the decision-making process for I4A, it has been determined that technological risks and social risks are crucial. This study will support managers, consultants, engineers, and policymakers in enhancing the overall quality of their decisions by limiting the adverse perception of I4.0 implementation efforts and mitigating the consequences of the COVID-19 pandemic on India's manufacturing industries. This research's concise but simple model is a valuable addition to new knowledge that abstractly covers the larger ambit in the context of the I4.0 vision. This distinguishes the research's distinctiveness as it is the first of its type.

5.2 Introduction

I4.0 is globally recognized as the fourth-generation industrial revolution, which integrates the IoT with an industrial value chain known as the IIoT. This initiative aims to build decentralized, intelligent, self-organizing value chains (Kagermann, 2015). It indicates that smart communication across factory components is one of the most crucial requirements for creating intelligent factories where machines and humans interact seamlessly (Papa et al., 2017). I4.0 aims to achieve 360^0 communication between humans and machines through intelligent, self-sufficient, and self-organizing networks. Adopting I4.0 techniques helps an organization deal with issues brought on by severe volatility and uncertainty. I4.0 differs from the traditional business by offering the seamless interconnectedness of all production machinery and equipment. The emergence of such technology solutions exhibits both opportunities and new challenges, including shorter product cycles due to rapid technological advancement and innovations, local and global market unpredictability, increased competitive pressure, information security, communication and dynamic data processing, and information security (Ben-Daya et al., 2017; Mogos et al., 2019). However, significant changes are anticipated due to the implementation of the I4.0 paradigm in the global business environment. This total digital transformation is expected to be led by emerging technologies, including BDA, IoT, IIoT, AI, ML, CC, Robots and Cobots, CPS, and AR and VR (Erboz, 2017). This could result in a potentially high-risk situation, which, if its adoption process is not thoroughly examined and planned, could have a very detrimental consequence on the overall sustainability of an industry.

Consequently, these I4.0 components must be carefully explored and understood before the bigger aspirations are jeopardized. The right approach and resources are needed to ensure responsible decisions in order to achieve safe and sustainable progress. Understanding, analyzing, and evaluating the causal relationship between the KPIs that influence not only various organizational risks but also decision quality is the main objective of this study.

MCDMs are robust and credible applications for solving numerous engineering and management problems (Zavadskas et al., 2018). However, only a limited number of studies have evaluated and examined the issues with I4.0 implementation associated with risks prioritizing using these techniques (Birkel et al., 2019; Moktadir et al., 2018). Additionally, it is discovered that none of the studies has considered the comparative examination of the relative performance of several MCDM methodologies applicable to the aforementioned problem. Focusing on all pertinent risks and taking them into account within one framework is another significant challenge for the company during the I4.0 transition phase. MCDM techniques have become the first choice to address this kind of issue, even though evaluating these risks based on the pertinent KPIs is incredibly challenging.

The DEMATEL approach is used in this investigation to establish direct and indirect causal relationships between the KPIs and how they affect one another. The CRITIC approach is employed to establish the objective weights of the study's KPIs (criteria), and the MABAC, PROMEETHEE II, MOORA, and COPRAS, MCDM methods are used to rank the most critical risks among the various possible I4.0 risks (alternatives). The performance rankings of these methods are further compared with Spearman's ranking correlation coefficient of all methods to determine the level of agreement between them. The effect of dynamic decision matrices on rank reversal (Stević et al., 2020; Yazdani et al., 2019a) and comparing the ranking obtained using six different sets of criteria (Yazdani and Chatterjee, 2018) are used in the sensitivity analysis study to demonstrate the robustness of the methods used.

However, it is noted that prior research did not present a comprehensive understanding of I4.0, exposing its implementation risks with regard to the important KPIs. The following five research questions are identified in order to achieve the study's objective.

Q. 1 What are the causal dependencies among the KPIs considered for the study? How do they influence each other?

Q.2 Which type of I4.0 risks is most prevalent and impacts the I4.0 implementation decision?

Q.3 Does the decision-making process alter much when I4.0 risks are ranked using different MCDM techniques?

Q. 4 How to test the solution's validity?

Q.5 What are the significance and implications of the developed integrated model?

This study has made an important contribution to the extant literature by identifying the research gap mentioned below, referring to the above research questions.

1. The study differs from others in that it examines the theoretical foundations of KPIs linked to I4.0 risks, prioritizes one of the most important I4.0 risks, and evaluates and analyses those risks using carefully chosen MCDM techniques, with a focus on validating the credibility of the preferred MCDM techniques.

2. An extensive literature review, the engagement of experts in the field, and the competence acquired through leading I4.0 endeavors are all factors that give credence to the study's findings.
3. The study's conclusions are convincingly justified, well substantiated, and grounded on previous investigations; as a result, it is an incredible contribution to the corpus of new knowledge.
4. This immaculately developed model will assist professionals, consultants, and scholars in the manufacturing industry in offering enhanced methodologies and approaches to boost performance within the I4.0 ecosystem through the prudent management of I4.0 KPIs and I4.0 risks.
5. In addition to the preceding, the study's ramifications and insights can offer a base for alleviating the I4A and enabling manufacturing companies to organize their assets and abilities to enforce sustainable growth.

The study is organized further as **Section 5.3** discusses the literature review. The research methodology adopted is described in **Section 5.4. The** elaboration on applying the integrated DEMATEL, CRITIC-MABAC, PROMEETHEE II, MOORA, and COPRAS methods is considered in **Section 5.5**. Results and discussion of findings are elaborated in **Section 5.6**, followed by conclusions and limitations of the study in **Section 5.7.**

5.3 Literature Review

In this investigation, the researcher initially outlined the prominent risks and influencing KPIs for the I4.0 implementation process through a comprehensive evaluation of the existing literature, interactions, and discussions with the I4.0 experts from manufacturing organizations. Therefore, by explicitly referring the databases like EBSCO, SCOPUS, IEEE, Science Direct, and Web of Science utilizing the below-mentioned search criteria, the literature study included sources with a high degree of legitimacy. Hence the key terms used to reach the utmost suitable sources of knowledge and information related to the research problem under consideration are "Smart factory," "Smart manufacturing," "Industry 4.0," "Industry 4.0 risk assessment," "Industry 4.0 adoption" and "Financial risk," "Legal framework," "Industry 4.0" and "Digital technologies," "Industry 4.0" and "Social dimensions," "Industry 4.0" and "Ecological Risk," "Industry 4.0" and "Industry 4.0" and "Political framework," "Industry 4.0" and "Sustainability," "Industry 4.0" and "Challenges," "Industry 4.0" and "Multi-Criteria Decision Making Techniques." This study has meticulously chosen potential reference studies from refereed journals with high-impact factors and listings in reputable indexes to preserve the literature review's high standards of quality and applicability. The content on MCDM methodologies was primarily examined in terms of their types, applications, and relevance to addressing current business issues in the present and future context available in the developed previous studies corpus. Citing a majority of the high, peer-reviewed, worldwide references aids in ensuring the integrity of the literature review. Further, the information is provided on the literature review findings regarding the ranking of I4.0 risks taken into account for the current study to finalize five of the most important risks and ten KPIs.

In addition to the technological challenges, cybersecurity concerns pose a vulnerability that could impede the I4A. The Zotob Worm, Stuxnet, BlackEnergy3, Duqu and Flamer, and the Ukraine Power Grid are a few cybersecurity threats that have forced the globe to think about its most dangerous perils (Prinsloo et al., 2019). The traditional perception of companies about the severity that can bring down business operations was toppled by these cyberattacks, leaving enormous scope for ambiguities related to the possible vulnerability. As a result, some firms are taking extra precautions while others are still in a dilemma. While some businesses are slowly but consistently embracing this threat as a prospect (Ojra, 2019). Massive automation and digitization in the production, value chain, and product design have produced infinite complexity and uncertainty, allowing experts to develop unique and innovative solutions. Additionally, this seems to have raised the need for organizations and policymakers to adopt the way forward for technology uses and formulate solutions for risks that have never emerged (Rajnai and Kocsis, 2017). According to Wu et al. (2019), the feasibility of I4.0 implementation depends on controlling threats and their components and taking steps to deal with uncertainty constraints. The operational risks arise in maintenance, tool use, and manufacturing operations. This relates to I4.0's constituent elements, including capital assets, machine environment, and manufacturing technologies. The real-time, dynamic, self-organizing cross-company value chain networks that substantially impact business operations are also frequently concerned about information security and data integrity (Tupa et al., 2017). In the study conducted by Birkel et al. (2019), economic, legal/political, social, ecological, and technological risks are highlighted in the risk assessment framework, which uses an expert interviewing methodology.

The related investigations were discovered to emphasize the literature on the use of the MCDM technique in studies related to I4.0 is elaborated further. A systemic competency model for workforce 4.0 has been established in a Turkey-based company where the study was done on the new I4.0 selection criteria for personnel. This study utilized the Fuzzy DEMATEL approach to evaluate the causal relationship between the selected criteria (Kazancoglu and Ozkan-Ozen, 2018). While taking into account the BWM and ELECTRE, a hybrid MCDM framework was designed to solve the difficulties in creating circular economy- and supply chain-based solutions (G. Yadav et al., 2020). The interval type-2 fuzzy AHP and the hesitant fuzzy TOPSIS method was utilized to develop the risk prioritizing framework for the I4.0 deployment but neglected to acknowledge the broader ambit of I4.0 risks (Colak et al., 2019). The current production system's automation diagnosis is evaluated using an AHP method to ensure it is in alignment with I4.0 in the study by (Saturno et al., 2017). Sevinç et al. (2018) used the AHP and ANP methods to analyze and evaluate the aspects of the I4.0 criteria pertaining to originality, organization, resources, and the environment. Bhagawati et al. (2019) performed an analysis using the DEMATEL method to assess the competency and sustainability of supply chain management by taking into account the performance factors and the interrelationships between them Moktadir et al. (2018) developed the framework for assessing the challenges of implementing I4.0 using the BMW technique, and they prioritized the challenges. The appropriate mitigation strategies should be made to move forward with the I4.0 deployment once the potential risks have been acknowledged. **Table 5.1** and **Table 5.2** states the I4.0 risks and KPIs was taken into consideration for the study, which is the outcome of the thorough literature review and expert discussions.

Table 5.1: Industry 4.0 Implementation Risks Considered for the Study

S.N.	**I4.0 Implementation Risks**	**Description Detailing**	**Literature Support**
1	Economic risks (A1)	Insufficient Financial asset allocation compliant with I4.0 and its poor understanding is the primary source of economic risks. Investment patterns and returns	Oesterreich and Teuteberg (2016) ; Piccarozzi et al. 2018); Müller et al. (2018a)

S.N.	I4.0 Implementation Risks	Description Detailing	Literature Support
		timelines largely influence decisions regarding investments in technology, digitalization, IT infrastructure, data handling capacity, and workforce management. The importance of competitors in the company’s exposure to financial risk cannot be overstated. The choice to make or acquire, which results in extensive consulting, outsourcing, and extraordinary interaction with professionals, may even compel the organization to confront financial risks.	
2	Technological risks (A2)	The technological risk is associated with a company’s data management, cybersecurity, cloud computing, and communication infrastructure, all of which require the appropriate combination of skills and expertise. Integration of the technological assets and infrastructure strategically and proficiently is essential to mitigating the risks posed by technology. The absence of technological standards and the company’s increased reliance on outside services to solve technology-related	Stefan et al. (2018); Veza et al. (2015); Alavian et al. (2020); Oztemel and Gursev, (2020)

S.N.	I4.0 Implementation Risks	Description Detailing	Literature Support
		issues both have the possibility of escalating the extent of the threat to the business.	
3	Legal and political risks (A3)	A robust tried, and tested foundation backed up by the government's legal and political policies to deal with the legal and political risks of I4.0 establishes a strong baseline for an organization's defined and disciplined growth. It can be achieved through straightforward and well-organized strategic plans. Thus, the scarcity of standards means that room still remains for discrepancies and ambiguities while progressing toward the I4.0 vision. In these situations, the organizations may not support it. The unified deployment of I4.0, which prioritizes data security, intellectual property, and data breaches, could be compromised by this, aggravating the legal and political risks of I4.0 deployment.	Hossain and Muhammad (2016); Hidayat (2020)
4	Environmental risks (A4)	There are close associations between environmental equilibrium and environmental risks. An increase in natural resource uses causes a significant detrimental effect on the surrounding	Sarkis and Zhu (2018); Bai et al. (2020)

S.N.	I4.0 Implementation Risks	Description Detailing	Literature Support
		ecosystem. Additionally, due to the extensive use, increased energy, power, and other resources are consumed, raising the amount of radioactive and poisonous materials and other waste products released into the environment. This trash interferes with the ecosystem's natural balance and creates contaminants.	
5	Social risks (A5)	Employees are impacted heavily due to expected changes due to the emergence of I4.0. Even if the transformation process is conducted professionally, the employees may experience the unexplained dread of losing their jobs, extreme work pressure, a decline in their health and sense of insecurity, a loss of work-life balance, and probable ambiguity. In the context of I4.0, this could lead to an increase in societal risks. Employee upskilling, counseling and training are a few strategies to assist staff in adjusting to the evolving workplace.	Stock et al. (2018);Piccarozzi et al. (2018); Müller (2019)

Table 5.2: The Key Performance Indicators for Prioritizing Industry 4.0 Implementation Risks

S.N.	KPIs for Prioritizing Industry 4.0 Implementation Risks	Description Detailing	Literature Support
1	Information security (KPI1)	The I4.0-enabled network is intended to maintain the privacy and security of enterprise data throughout the whole network. Only a limited number of authorized personnel should be allowed access to this information when needed. Standard verification, processing, and validation techniques are used to save and edit the data. All system-gathered information from various sources should be safely controlled.	Geissbauer et al. (2016); Mogos et al. (2019)
2	Integrity (KPI2)	It is the authenticity of all the sources used to gather the data. The information and applicable system are reliable and accurate according to standards and	Corallo et al. (2020);Dutta et al. (2021)

S.N.	KPIs for Prioritizing Industry 4.0 Implementation Risks	Description Detailing	Literature Support
		processes that are compliant with I4.0.	
3	Availability (KPI3)	Resources and information are made available to the designated contact person as per requirement. Key indicators of the I4.0-compliant system's resource availability include network connectivity, integration, and collaboration throughout the whole network.	Tupa et al. (2017);(Vaidya et al., 2018)
4	Quality (KPI4)	This features robust infrastructure support and network connectivity for IoT devices, CPS, AI, BDA, IoT, Cloud applications, VR, AR, ML, and other related technologies.	Bibby and Dehe (2018); Schumacher et al. (2019)
5	Performance (KPI5)	It is the ability to generate better intrinsic worth by utilizing the appropriate IT infrastructure, technology, and skill sets. Strategic leadership and	Cimini et al. (2017); Maresova et al. (2018)

S.N.	KPIs for Prioritizing Industry 4.0 Implementation Risks	Description Detailing	Literature Support
		organizational strategy both have an impact on an organization’s performance.	
6	Design (KPI6)	Planning of products and procedures to develop an I4.0-compliant company model.	Benešová and Tupa, (2017);Ivanov et al. (2019)
7	IT Infrastructure (KPI7)	The connectivity and networking resources, equipment, and machinery are in line with I4.0 standards, including self-regulating, self-organizing, CPS, IoT, software, hardware, etc.	Jun et al. (2017); Habibi Rad et al. (2021)
8	Interoperability (KPI8)	It is a system’s collaboration, coordination, integration, and self-organization capacity.	Gökalp et al.(2017); Ibarra et al.(2018)
9	Flexibility (KPI9)	It is how the system responds to changes, disruptions, and systemic issues. It can be characterized as the degree of handling agility and adaptability. The best way to define flexibility is as a	Mittal et al., (2018a); Fatorachian and Kazemi (2018)

S.N.	KPIs for Prioritizing Industry 4.0 Implementation Risks	Description Detailing	Literature Support
		quick reaction to changing demand and product adaption.	
10	Cost (KPI10)	Cost is composed of investments in education, hardware, software, technical support, servicing, sensors, networking, infrastructure development, maintenance, and skill development to make the system compliant with I4.0.	Mittal et al., (2018a); Salam (2019)

5.4 Research Methodology

This study utilizes the most popular MCDM techniques described in this chapter's earlier section. This study aims to assess the I4.0 risks based on the I4.0 KPIs and investigate the causal relationships between the KPIs under consideration. It is observed from the past literature that studies are carried out on current models, theories, and mechanisms used in an organization on a very limited ambit of the I4.0 risks related issues (Birkel et al., 2019; Tupa et al., 2017). In this context, some models and frameworks were considered irrelevant and out of context because they are focused on traditional philosophies and assumptions.

Therefore, there is room for building an extremely precise and relevant model to accommodate both present and future needs that will resolve a company's I4.0 risks-relevant issues. Thus, **Figure 5.1** provides a schematic representation of the developed model's step-by-step approach to addressing the current research problem. Phase I of this analysis offers a comprehensive overview of the procedure used to determine the criteria and alternatives for evaluating and assessing the I4.0 risks. Phase II was devoted to selecting appropriate MCDM methods to meet the needs of the problem under consideration. Phase III validated the Phase II outcome through a systematic sensitivity analysis and reported critical findings and recommendations.

The detailed selection process of these methodologies is further discussed in this section. MCDM methods are widely used in solving real-life situation problems where decision-makers encounter challenges in selecting conflicting criteria. As evident from research, MCDM methods have proved their worthwhile selecting the best alternative out of the available feasible options through a systematic decision-making approach. The choice of the right method is guided by its ability to handle complexity, ease of applications, and capabilities to approach the true solution (Athawale and Chakraborty, 2011). Prospective MCDM methods were compared on different dimensions like robustness, consistency, quality, and reliability of the process for making decisions. This study considers the following six MCDM methods, i.e., DEMATEL, CRITIC, MABAC, PROMEETHEE II, MOORA, and COPRAS.

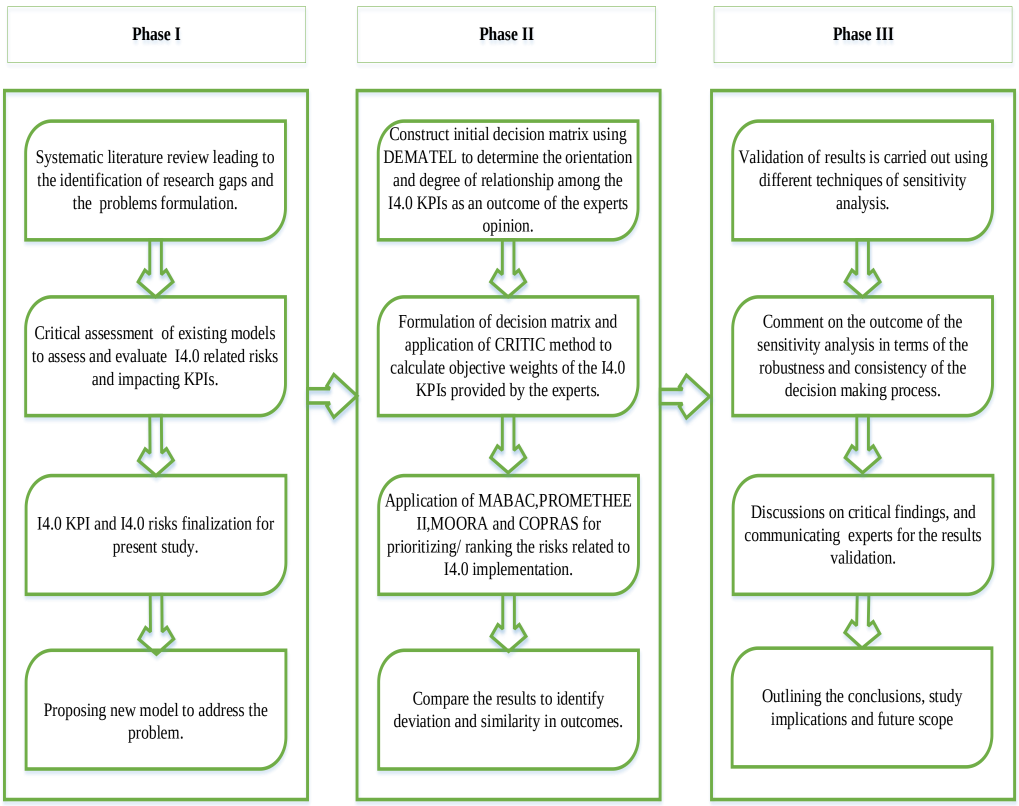

Figure 5.1: Framework for Risks Assessment for I4.0 Implementation

5.4.1 The MCDM Methods Chosen for the Study

The hierarchical framework is developed among the identified I4.0 KPIs, and the I4.0 risks are elaborated for the risk evaluation in **Figure 5.2.** Further, the application of MCDM approaches is covered in the following section.

5.4.1.1 Decision-Making Trial and Evaluation Laboratory Method (DEMATEL)

One of the MCDM tools, DEMATEL, is used in the current study to establish an interrelationship structure between the criteria considerations made during the process of decisions. The Geneva Research Center's Battelle Memorial Association gets the credit for developing this method (Fontela and Gabus, 1976). This method compares and assesses the degree of influence one KPI has on the other and the direct and indirect causal relationships between the KPIs. Additionally, the technique offers a comprehensive visual structural matrix and causal diagram. This method is based on the concept of digraphs that separates the group of attributes into cause-and-effect groups to resolve complex decision-making problems. The DEMATEL method comprises the following steps.

Step 1: Formulate the Initial Direct Relation Matrix (*D*)

A pairwise comparison matrix is constructed to determine the direct effect of each i^{th} KPI on each of the j^{th} KPIs. The linguistic expressions provided by the experts are encoded in the numbers. Further, this input is used to develop the pairwise comparison matrix among the KPIs. An initial direct relationship matrix (D) is constructed using a five-point numeric scale. The scale is expressed numerically as 0-No, 1-Low, 2-Medium, 3-High, and 4-Extremely High Influence.

The average initial direct relation matrix (*D*) is shown below where d_{ij} denotes the extent to which the i^{th} KPI influences the j^{th} KPI and is considered as the average value of the ratings provided by all experts.

$$D=\begin{bmatrix} 0 & d_{12} & \cdots & d_{1j} & \cdots & d_{1n} \\ d_{21} & 0 & \cdots & d_{2j} & \cdots & d_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ d_{n1} & d_{n2} & \cdots & d_{nj} & \cdots & 0 \end{bmatrix} \ldots\ldots\ldots\ldots\ldots(1)$$

Step 2: Normalize the average initial direct relation matrix (*A*)

The following equations use the average initial direct relation matrix (D) to create the normalized average direct relation matrix (A)

$A = k.D$ …………… (2)

Where

$k = \frac{1}{\max_{1 \le i \le n} \left(\sum_{j=1}^{n} d_{ij} \right)}$, *i, j=1,2,…,n* ……………(3)

Step 3: Calculate the Total Relation matrix (*T*)

The total relation matrix is developed using the following equation, where t_{ij} represents the indirect effect of the i^{th} KPI on the j^{th} KPI. *I* indicate an Identity matrix, and the total association among each pair of criteria is denoted by *T*.

$$T = \left[t_{ij}\right]_{n\times n}, \quad i, j=1,2,\dots,n$$

$$\begin{aligned} T &= A + A^2 + A^3 + \cdots + A^k \\ &= A(I + A + A^2 + \cdots + A^{k-1})[(I - A)(I - A)^{-1}] \\ &= A(I - A^k)(I - A)^{-1} \\ &= A(I - A)^{-1}, \quad \text{when } k \to \infty, A^k = [0]_{n\times n} \end{aligned}$$ ……………(4)

Step 4: Calculate the sum of rows and columns of the *T* matrix.

Equations (5) and (6) compute the sum of rows and columns of the *T* matrix denoted by vector R_i and C_j, respectively.

$R_i = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} = [t_i]_{n\times 1}$, *i =1,2,…,n* …………… (5)

$C_j = \left[\sum_{i=1}^{n} t_{ij}\right]_{1\times n} = [t_j]_{n\times 1}$, *j=1,2,…,n* …………… (6)

Step 5: Set the threshold value ($\propto$)

The average of elements of the *T* matrix is considered as the threshold value ($\propto$), as shown in equation (7)

$\propto = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} [t_{ij}]}{N}$ …………… (7)

T matrix provides information on KPIs' effect over another. For decision-makers, therefore, it is important to set a threshold value to exclude any marginal impacts. Only effects involving a higher value than the set threshold value were considered meaningful and expressed in a digraph **(Figure 5.3).**

Step 6: Develop a Casual Diagram

The (Ri+Cj) values, which represent the relative relevance of the KPIs, are plotted on the x-axis to create the causal diagram. The sort of link between the KPIs is shown by the (Ri-Cj) on the y-axis. Greater relevance results from higher (Ri+Cj) values, and vice versa. The diagram's visual representation, reflected in **Figure 5.4,** separates the criteria into two groups: cause and effect. According to the diagram, KPIs with a positive value of (Ri-Cj) belong to the cause group, while others with negative values belong to the effect group. This confirms that the DEMATEL method is a very useful tool for visualizing the relationships within the set of KPIs considering the cause-and-effect groups and the internal dependencies. This method's advantage is displaying the indirect relationship through the cause and effect model, which makes it effective for analyzing the structure and relationship of the system's complex elements. More emphasis is given to trigger groups because these KPIs are the driving force behind the mechanism that affects the impact group KPIs. Its prime focus on the cause-oriented approach has made this method more popular and the first choice of the decision-makers when it comes to solving a complex problem. A digraph is developed to visualize the contextual relationship among the KPIs considered for the study. Due care should be taken in working with DEMATEL regarding the time spent formulating the pair comparison matrix between KPIs. This implies that the information obtained from the experts used to make the initial direct relationship matrix ensures that the expected result is close to the real solution, making the outcome more credible.

5.4.1.2 Criteria Importance Through Inter-criteria Correlation (CRITIC)

The CRITIC method was first proposed by Diakoulaki et al. (1995) as a framework to resolve the dilemma of choosing between competing criteria. When decision-makers disagree on how to calculate the weights of criteria and are unable to compare various criteria because of ambiguity, this is the best method to do it (Diakoulaki et al., 1995). In the CRITIC method, the decision matrix is ascertained by consulting and discussing with decision-makers. Then, the criteria contrast is found by using the standard deviation of normalized criterion values from each column and the correlation coefficients of all pairs of columns in the decision matrix (Madić and Radovanović, 2015; Tuş and Aytaç Adalı, 2019). The steps listed below make up the CRITIC approach.

Step 1: Construct the decision matrix X, which describes the performance of different alternatives concerning criteria.

$$X = \left[X_{ij}\right]_{mxn} = \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1n} \\ X_{21} & X_{22} & \cdots & X_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ X_{m1} & X_{m2} & \cdots & X_{mn} \end{bmatrix} \quad (i=1,2,3....,m, \text{ and } j=1,2,...,n) \quad \ldots\ldots\ldots (8)$$

Here X_{ij} is the performance value of i^{th} alternative concerning j^{th} criteria, *m* is the number of alternatives, and *n* is the number of criteria.

Step 2: Generate the normalized decision matrix utilizing the formulae below

$\overline{X}_{ij} = \frac{X_{ij} - X_{ij}^{worsrt}}{X_{ij}^{best} - X_{ij}^{worst}}$ For benefit criteria …………… (9)

$\overline{X}_{ij} = \frac{X_{j}^{best} - X_{ij}}{X_{ij}^{best} - X_{ij}^{worst}}$ For non-benefit criteria …………… (10)

Step 3: Calculate the standard deviation σ_j for each criterion. Construct a symmetric matrix of *n* x *n* with an element r_{jk} , i.e., the linear correlation coefficient between the vectors X_j and X_k .

Step 4: Calculate the measure of conflict created by criteria *j* concerning decision situations defined by the remaining criteria.

$\sum_{k=1}^{m}(1 - r_{jk})$ …………… (11)

Step 5: Determine the quantity of information QI_j for each criterion. In MCDM, problem information confined consists of conflict of decision criteria and contrast intensity of the decision criteria.

$QI_j = \sigma_j * \sum_{k=1}^{m}(1 - r_{jk})$ …………… (12)

Step 6: Utilize the following expression to determine the objective weights for each criterion.

$W_j = \frac{QI_j}{\sum_{k=1}^{m} QI_j}$ …………… (13)

This method gives a higher weight to the criteria with a low correlation with other criteria and a high standard deviation (Madić and Radovanović, 2015). It signifies that the criteria's relative importance in the decision-making problem is indicated by the higher values of $QI_{j,}$ which provide more information about the criteria (Tuş and Aytaç Adalı, 2019).

5.4.1.3 *Multi-Attributive Border Approximation Area Comparison Method (MABAC)*

At the University of Defense's research center in Belgrade, the MABAC method was developed for the first time. This method uses straightforward mathematical equations and a systematic approach to problem-solving, mimicking the human decision-making process (Chatterjee et al., 2017; Gigović et al., 2017; Pamučar et al., 2018). The procedural approach of the MABAC method is listed below.

Step 1: Construct the decision matrix (X) as indicated in equation (8)

Step 2: Construct the normalization decision matrix (R).

The following equations represent the identification of elements of the normalized decision matrix

$x_{ij} = \frac{x_{ij}-x_i^-}{x_i^+-x_i^-}$ for beneficial criteria …………… (14)

$x_{ij} = \frac{x_{ij}-x_i^+}{x_i^--x_i^+}$ for non-beneficial criteria …………… (15)

Here X_i^+ and X_i^- are the maximum and minimum values of the *j*th criteria according to the alternatives.

Step 3: Determine the weighted normalized decision matrix (V) using the below equation:

$V_{ij} = W_j x_{ij} + W_j$ …………… (16)

Here, W_j refers to the weight coefficient of criteria and x_{ij} represents the elements of the normalized decision matrix (R).

Step 4: Calculate the border approximation area (BAA) matrix (B)

The elements of the matrix (B) for each criterion are determined according to

$b_j = \left(\prod_{i=1}^{m} V_{ij}\right)^{1/m}$ …………… (17)

Then, the Border approximation area matrix (B) is developed for each criterion. Here, V_{ij} refers to the elements of the weighted normalized decision matrix (V) and b_j refers to the BAA for the *j*th criteria.

Step 5: Calculate the distance matrix of alternatives (Q) from the BAA

$Q = V - B$ …………… (18)

Step 6: Calculate the criteria function S_i values for ranking the alternatives

Here, S_i is calculated as the sum of the distance of the alternative from BAA, i.e., q_{ij} as shown in the equation below. The higher value of S_i is considered the best value and ranked first.

$$S_i = \sum_{j=1}^{n} q_{ij} \quad \text{.............. (19)}$$

5.4.1.4 Preference Ranking Organization Method for Enrichment Evaluation (PROMEETHEE II)

The PROMETHEE II method was invented by Brans and Vincke (1985) and Doumpos and Zopounidis (2004). The PROMETHEE I has the limitation of only offering a partial ranking of the decision alternatives. At the same time, the PROMETHEE II approach fixes PROMETHEE I's flaws and is capable of providing a complete ranking of the alternatives. This method includes discrete alternatives to meet quantitative and qualitative requirements from an interactive MCDM perspective. This method compares the alternatives pairwise to establish the preference function for each criterion. Thus based on the net outranking flow for each alternative, as explained below, the best alternative is chosen (Doumpos and Zopounidis, 2004; Hajkowicz and Higgins, 2008). The procedural steps of the PROMEETHEE II method are discussed below.

Step 1: Establish the decision matrix (X) as indicated in equation (8)

Step 2: Normalize the decision matrix using the following equation

$$R_{ij} = \frac{[X_{ij} - min(X_{ij})]}{[max(X_{ij}) - min(X_{ij})]} \text{ , for beneficial criteria, } (i = 1,2,\ldots,m; j = 1,2,\ldots.,n) \quad \text{............... (20)}$$

$$R_{ij} = \frac{[max(X_{ij}) - X_{ij}]}{[max(X_{ij}) - min(X_{ij})]} \text{ , for non-beneficial criteria, } (i = 1,2,,\ldots m; j = 1,2,\ldots.n) \quad \text{..........(21)}$$

Here, the X_{ij} refers to the performance measure of i^{th} alternative concerning the j^{th} criterion.

Step 3: Calculate the preference function, $P_j(a,b)$

$$P_j(a,b) = 0 \;\; if \quad R_{aj} \leq R_{bj} \rightarrow D(M_a - M_b) \leq 0 \text{ .... } (22)$$

$$P_j(a,b) = (R_{aj} - R_{bj}) \;\; if \quad R_{aj} \rangle R_{bj} \rightarrow D(M_a - M_b) \rangle 0 \text{ .... } (23)$$

Step 4: Calculate the aggregated preference function considering the criteria weights. Thus, the Aggregate preference function is given as,

$$\pi(a,b) = \left[\sum_{j=1}^{n} W_j P_j(a,b)\right] / \sum_{j=1}^{n} W_j \text{ .... } (24)$$

Step 5: Determine the outgoing and incoming outranking flows as follows:

$\phi^+ = \frac{1}{m-1} \sum_{b=1}^{m} \pi(a,b)$, outgoing (positive) flow for a^{th} alternative, $(a \neq b)$

.... (25)

$\phi^- = \frac{1}{m-1} \sum_{b=1}^{m} \pi(b,a)$ $(a \neq b)$, incoming (negative) flow for a^{th} alternative

.... (26)

Step 6: Calculate the net outranking flow for each alternative

$$\phi(a) = \phi^+(a) - \phi^-(a) \text{ .... } (27)$$

Step 7: Determine the ranking of the alternatives. The best option is the one with the highest value $\varphi(a)$.

5.4.1.5 Multi-Objective Optimization based on Ratio Analysis (MOORA)

The MOORA method is proposed by Brauers et al. (2008). This method is preferred to study alternative responses to objectives where ratios can work. This method simultaneously optimizes two or more contradictory attributes/criteria, subject to specific constraints. The procedural steps of the MOORA method are discussed below.

Step 1: Generate the decision matrix (X) as shown in equation (8)

Step 2: Compute the normalized decision matrix using a vector normalization method, as shown in the following equation.

$\bar{r}_{ij} = \frac{x_{ij}}{\sum_{j=1}^{m} {x_{ij}}^2}$ where $(i = 1,2,,...m;\; j = 1,2,....n)$ .... (28)

Here, $\bar{r}_{ij}$ is referred to as the normalized performance value of i^{th} alternative w.r.t. j^{th} criteria. Here m is the number of alternatives, and n is the number of criteria.

Step 3: Determine the weighted normalized decision matrix as shown in the following equation $V_{ij} = W_j * \bar{r}_{ij}$ where $(i = 1,2,...m; j = 1,2,....n)$ …………… (29)

Here, W_j is referred to as the weight coefficient of j^{th} criteria.

Step 4: For all alternatives, calculate the overall rating of beneficial and non-beneficial criteria using the following equation

$y_i^+ = \sum_{j=1}^{j=g} V_{ij}$, where $j=1,2,......g$, for the beneficial criteria …………… (30)

$y_i^- = \sum_{j=g+1}^{j=n} V_{ij}$, where $j=g+1,g+2,....n$, for non-beneficial criteria……………(31)

Step 5: Calculate the overall performance index using the following equation

$y_i = y_i^+ - y_i^-$ …………… (32)

Step 6: Obtain the final ranking of alternatives using y_i Values. The higher value of y_i is considered the best alternative.

5.4.1.6 Complex Proportional Assessment Method (COPRAS)

This method was introduced first by Zavadskas et al. (1994). The alternatives are assessed using this method based on the available alternatives' importance and degree of utility while considering the conflicting criteria. The procedural steps of this method are explained below.

Step 1: Construct the decision matrix (X) as shown in equation (8)

Step 2: Compute the normalized decision matrix using the following equation

$\bar{r}_{ij} = \frac{x_{ij}}{\sum_{j=1}^{m} x_{ij}}$ $(i = 1,2,...m; j = 1,2,....n)$ …………… (33)

Here $\bar{r}_{ij}$ is referred to as the normalized performance value of i^{th} alternative w.r.t. j^{th} criteria, m is the number of alternatives, and n is the number of criteria.

Step 3: Determine the weighted normalized decision matrix as shown in the following equation

$V_{ij} = W_j * \bar{r}_{ij}$ $(i = 1,2,,...m;\ j = 1,2,....n)$ .... (34)

Here W_j is the weight coefficient of the j^{th} criteria.

Step 4: Calculate the sum of weighted normalized values for beneficial (P_j) and non-beneficial (R_j) using the following equations

$P_j = \sum_{i=1}^{k} V_{ij}$, where k is the number of beneficial criteria .... (35)

$R_j = \sum_{i=1}^{n-k} V_{ij}$, where (n-k) is the number of non-beneficial criteria .... (36)

Step 5: Calculate the relative significances or priorities of alternatives using the following formula

$Q_j = P_j + \frac{\sum_{j=1}^{m} R_j}{R_{j*} \sum_{j=1}^{m} \frac{1}{R_j}}$ .... (37)

Step 6: Calculate the quantitative utility (N_j) of alternative for j^{th} criteria using the following formula

$N_j = \frac{Q_j}{Q_{max}} * 100\%$ .... (38)

Where Q_{max} denotes maximum relative significance value.

Thus, this technique examines the proportional and direct dependence of significance and utility degree of alternatives. The utility of alternatives has a value between 0% and 100%, and the larger value determines the alternative ranks as the best.

5.4.1.7 Spearman's Correlation Coefficient and Kendall Coefficient of Concordance Calculation of MABAC, PROMEETHEE II, MOORA, COPRAS Methods Results

The similarity between two sets of ranks can be determined using Spearman's rank correlation coefficient value (Sheskin, 1996). Its value often falls within -1 and +1, with +1 signifying a complete match between two rank sequences. Kendall's coefficient of concordance value, which ranges from 0 to 1, is used to determine how similar two sets of rankings are. A value of 1 indicates a perfect match (Hajkowicz and Higgins, 2008). Calculate Spearman's correlation coefficient and Kendall's coefficient of concordance for comparative analysis of the ranking performance obtained from the results of MABAC, PROMEETHEE II, MOORA, and COPRAS methods.

5.4.1.8 Sensitivity Analysis:

The sensitivity analysis's primary objective is to assess the robustness of the methods and tools utilized to find solutions to the problem under investigation. On this note, two sensitivity analysis methods are used to find the sturdiness of the findings of the four MCDM techniques mentioned earlier.

5.4.1.8.1 Effect of Dynamic Decision Matrices on Rank Reversal

In this method, the ranking obtained by all methods, i.e., MABAC, PROMETHEE II, MOORA, and COPRAS earlier, is taken as the input for the sensitivity analysis for the first iteration. In each succeeding iteration, the alternative with the lowest rank was removed from the input decision matrix, and a new ranking was generated. The cycle continued until the last two alternatives remained in the matrix. The same process was repeated for all methods, i.e., MABAC, PROMETHEE II, MOORA, and COPRAS.

5.4.1.8.2 Comparing the Ranking Obtained using Six Different Sets of the Criteria Weights

Random six tests were considered to conduct sensitivity analysis through this technique. This method used the weights of ten criteria alterations randomly for six cycles. Further, these six cycles were considered for ranking alternatives for each cycle.

5.5 Application of Integrated DEMATEL-CRITIC- MABAC, PROMEETHEE II, MOORA, and COPRAS Methodology

This section goes into detail about how the intended integrated research framework is used. As shown by earlier studies, the MCDM problem's findings have always benefited from the expertise of experts. The selection of the experts included taking into account their credentials and abilities to address the research questions mentioned earlier. The twelve experts' group is considered pertinent and reliable for this investigation as suggested by Murry and Hammons (1995). Ten notable KPIs and five critical risks were endorsed by their high-level discussion and thorough SLR as being adequate to create a robust and reliable model. **Section 5.3** provided details on I4.0 risks and KPIs considered for this investigation.

The academic and industrial profile of the focused group is as follows:

1. Academicians: Four professors in the group belonged to Mechanical Engineering, Industrial Engineering, Information Technology, and Management from reputed universities in India.
2. Experts from Industry: All six experts from the industries have brought a different level of experience by virtue of their position as owners, CEO, senior-level managers, and middle-level manager in companies in the automobile industry, ammunition hardware manufacturing, furniture manufacturing, plastic industry, and IT industry.
3. Consultant: The presence of a consultant from the I4.0 domain brought a neutral viewpoint.
4. Data scientist: The expert in analytics added the perspective and importance of data handling in the success of I4A.

The industry experts who contributed to this study come from major large public and private sector manufacturing enterprises in Maharashtra, India. These organizations have made recent decisions to adopt I4.0 technologies and practices fully. This is in line with the business's adopted objective to maintain its competitiveness in domestic and international markets. They started by using predictive analytics to monitor and manage machine health conditions to reduce the risk of production disruptions and losses. Additionally, sensor installations are used to gather data through IIoT devices, moving toward adopting real-time decision-making. These businesses are investing a lot of time, effort, and ingenuity into designing the architecture, creating the required infrastructure, and adhering to I4.0. At the same time, being agreeable to the necessity of a framework for risk assessment to strengthen the way forward for I4.0 deployment. The most notable feature of these activities is that all company departments are working simultaneously to make the business I4.0 compliant. Efforts are being taken to achieve this through training, educating, and motivating the staff to create innovative new methods using cutting-edge technologies like CPS, IIoT, robotics and cobots, CC, 3D printing, blockchain, ML, AI, digital twin, and VR and AR. Thus, to enable employees' real-time experience in a virtual environment, VR and AR technologies are widely employed to train them in many company divisions. The study deliberately selected these companies to reveal the technological advances happening in the manufacturing ecosystem. Despite the companies' active I4A vision through ongoing innovation, research, and development, these businesses are nonetheless confronted with a lot of concern about risk assessment and mitigation. The businesses concur that the I4A framework is smart despite the challenges. The companies have begun organizing their research efforts and allocating significant resources to them. This demonstrates the firm's dedication to transferring toward I4.0 as soon as possible. This investigation aims to provide a model for risk assessment and mitigation as the primary issue for all future strategy development.

A comprehensive analysis of the literature, in-depth interviews, and discussions with twelve experts from the companies mentioned above help choose the alternatives, i.e., risks for I4A, and the criteria, i.e., I4.0 KPIs, on which the risks are prioritized. These experts selected has a broad range of knowledge, exposure, experience, and competence in projects related to I4.0. One of the study findings that will significantly assist the organizations during the course of making decisions is the evaluation of the direct and indirect causal relationships between the KPIs chosen for the study and their level of influence on one another. It has been noted that prior research has paid very little attention to the decision-making related to risk management in relation to I4.0 and its evaluation through the MCDM. This encourages the researcher to perceive this concern as extremely urgent and certainly worthy of attention for the current investigation.

Figure 5.2 illustrates the framework for decision-making that was developed in this study for the I4.0 risks assessment.

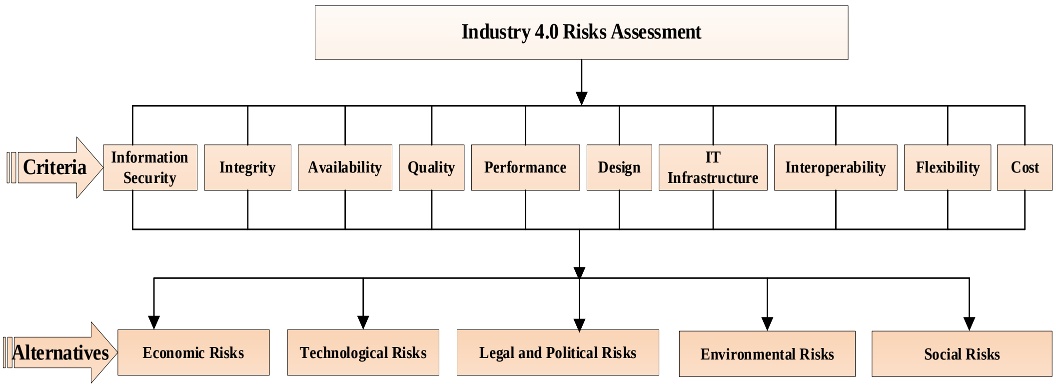

Figure 5.2: The Industry 4.0 Implementation Risks Assessment Hierarchy

Initially, as mentioned in **Section 5.4.1.1,** the experts were requested to rate the relationship importance between each KPI using an integer scale utilizing the

DEMATEL approach. The pairwise comparisons matrix was developed to map the intensity of the relationship between the KPIs. Once the group of experts agrees on the interrelationship between the KPIs, the Average Initial direct relation matrix (D), i.e., a 10x10 matrix, is created and explained in **(Section 5.4.1.1 step 1, Table 5.3).** Further Total Relation Matrix (T) is developed, and the sum of rows and columns of the *T* matrix, i.e., R_i and $C_{j,}$ values are calculated using **(steps 2,3, and 4 Sections 5.4.1.1, Table 5.4). Step 5** is used to set threshold value (∝) is determined by averaging the (T) matrix's entries., i.e., 0.2102. Only the values greater than the threshold value are considered to draw a digraph, as shown in **Figure 5.3** and indicated by (*) in the total relation matrix (T). The arrow maps all the KPI interaction values greater than threshold values. The diagram illustrates the KPI's contextual link. **Step 6, Section 5.4.1.1**, is followed to develop a causal diagram referring to **(Table 5.5).** Prominence causal values **Table 5.5** and the causal diagram for KPIs **(Figure 5.4)** depict the ten evaluation KPIs visually separated into divisions of effects and causes. The cause group belongs to Information security (KPI1), Quality (KPI4), Integrity (KPI2), Interoperability (KPI8), Availability (KPI3), and the effect group belongs to cost (KPI10), Flexibility (KPI9), Design (KPI6), Infrastructure (KPI7), Performance (KPI5).

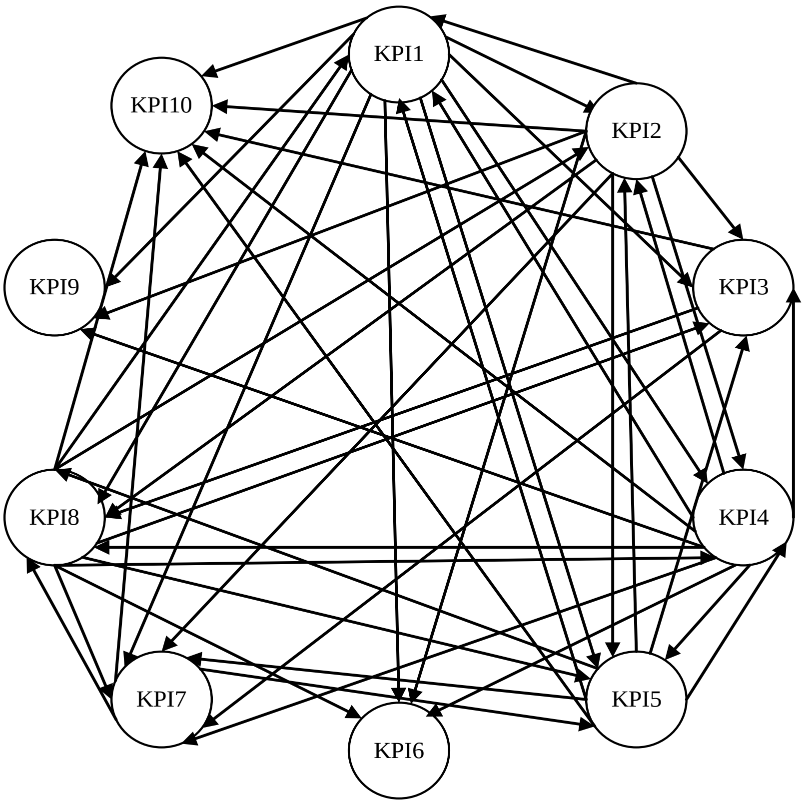

Figure 5.3: Diagraph Representing the Prominent KPIs Relationship

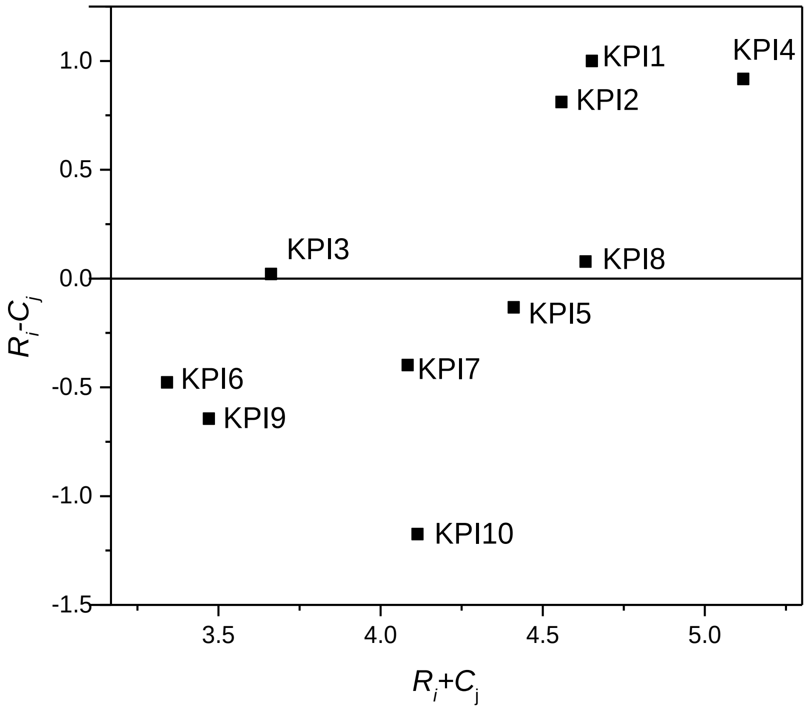

Figure 5.4: Causal Diagram Representing the KPIs in Cause and Effect Group

Table 5.3: Average Initial Direct Relation Matrix (D)

Criteria	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9	KPI10
KPI1	0.0000	2.3333	3.5000	3.3333	3.4167	3.3333	2.4167	2.5833	2.5833	3.4167
KPI2	3.4167	0.0000	2.4167	3.5000	3.5000	2.5833	2.4167	2.4167	2.5000	2.3333
KPI3	0.5000	1.5000	0.0000	1.6667	1.4167	1.6667	2.3333	2.3333	2.4167	2.5000
KPI4	3.3333	3.4167	2.3333	0.0000	3.2500	3.5000	3.4167	3.4167	2.5833	3.3333
KPI5	2.3333	2.5000	1.5000	2.5833	0.0000	1.5000	2.4167	2.5000	1.4167	2.5000
KPI6	1.6667	1.5833	0.7500	1.4167	1.5000	0.0000	0.5000	1.6667	1.6667	2.5000
KPI7	1.6667	1.4167	1.5000	1.6667	2.4167	1.5833	0.0000	2.5833	1.5833	3.5000
KPI8	2.5833	2.5833	2.5833	2.5833	2.4167	2.5833	2.4167	0.0000	1.4167	2.5833
KPI9	0.6667	1.5833	0.6667	1.6667	1.5833	1.5000	1.5000	1.6667	0.0000	2.5000
KPI10	0.7500	0.7500	1.5000	1.6667	1.6667	1.5833	2.4167	2.3333	1.6667	0.0000

Table 5.4: Total Relation Matrix (T)

Criteria	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9	KPI10	R
KPI1	0.1713	0.2517*	0.2755*	0.3065*	0.3175*	0.3036*	0.2913*	0.2925*	0.2624*	0.3536*	2.8259
KPI2	0.2707*	0.1694	0.2473*	0.292*	0.3125*	0.266*	0.2795*	0.2825*	0.2469*	0.3176*	2.6845
KPI3	0.1365	0.1657	0.1091	0.1813	0.1923	0.1783	0.2202*	0.2197*	0.1989	0.2395*	1.8415
KPI4	0.2876*	0.2933*	0.2613*	0.2119*	0.3363*	0.3145*	0.3324*	0.3362*	0.2687*	0.3754*	3.0176
KPI5	0.2152*	0.2126*	0.1848	0.2292*	0.1641	0.1956	0.2395*	0.239*	0.1915	0.2674*	2.1389
KPI6	0.1412	0.1354	0.1074	0.152	0.1542	0.0977	0.1298	0.1569	0.1392	0.1996	1.4134

Criteria	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9	KPI10	R
KPI7	0.1631	0.1611	0.1589	0.1756	0.2159*	0.1718	0.1385	0.2203*	0.168	0.2697*	1.8429
KPI8	0.2226*	0.2306*	0.2243*	0.2483*	0.262*	0.24*	0.257*	0.1794	0.2052	0.2856*	2.355
KPI9	0.1082	0.1357	0.1119	0.1537	0.1597	0.1439	0.1596	0.1637	0.0894	0.2062	1.432
KPI10	0.1096	0.1178	0.14	0.1502	0.1571	0.1459	0.193	0.1871	0.1393	0.1296	1.4696
C	1.826	1.8733	1.8205	2.1008	2.2716	2.0573	2.2408	2.2773	1.9095	2.6442	

Table 5.5: Prominence Causal Values

Criteria	R_i	C_j	R_i-C_j	R_i+C_j	Criteria Group
KPI1	2.8259	1.826	0.9999	5.1184	Cause
KPI2	2.6845	1.8733	0.8112	4.5578	Cause
KPI3	1.8415	1.8205	0.021	3.662	Cause
KPI4	3.0176	2.1008	0.9168	4.6519	Cause
KPI5	2.1389	2.2716	-0.1327	4.4105	Effect
KPI6	1.4134	2.0573	-0.6439	3.4707	Effect
KPI7	1.8429	2.2408	-0.3979	4.0837	Effect
KPI8	2.355	2.2773	0.0777	4.6323	Cause
KPI9	1.432	1.9095	-0.4775	3.3415	Effect
KPI10	1.4696	2.6442	-1.1746	4.1138	Effect

Further, the findings obtained by CRITIC, MABAC, PROMEETHEE II, MOORA, and COPRAS methods, as mentioned in **Sections 5.4.1.2 to 5.4.1.6,** are elaborated below. The Initial decision matrix was obtained by aggregating the rating provided by an individual expert using 5 points Likert scale as suggested by (Camparo, 2013), as 1-Very low importance and 5-Very high importance. The aggregate decision matrix is presented in **Table 5.6.** The CRITIC method obtains the KPIs weights, as explained in **Section 5.4.1.2,** and is expressed in **Table 5.7.** The I4.0 risks ranks obtained by MABAC, PROMEETHEE II, MOORA, and COPRAS is illustrated in **Table 5.8,** as explained in **Section 5.4.1.3 to 5.4.1.6**. Spearman's correlation coefficient among these four methods is 1, as all methods show the same ranking sequence **Section 5.4.1.7 Table 5.8.**

After these four approaches rank, a sensitivity analysis is undertaken to verify the reliability of the rankings produced by these four methods. As discussed in **Section 5.4.1.8,** the result of sensitivity analysis using the effect of dynamic decision matrices on the rank reversal method is presented in **Table 5.9, Section 5.4.1.8.1. Figure 5.5** shows the comparison of rank reversal obtained by MABAC (a), PROMEETHEE II (b), MOORA (c), and COPRAS (d).

As discussed in **Section 5.4.1.8.2**, sensitivity analysis compares the ranking obtained by MABAC, PROMEETHEE II, MOORA, and COPRAS methods using six different sets of the KPI weights, the six trial weights of KPIs are presented in **Table 5.10.** The result obtained from sensitivity analysis in each test for all the above four methods is elaborated in **Table 5.11. Table 5.12** expressed the performance result of the above four methods during sensitivity analysis using six different sets of the KPIs by deriving Spearman's correlation coefficients and Kendell's coefficient of concordance for the above four methods.

Table 5.6: Aggregate Decision Matrix for I4.0 Implementation Risk Assessment

KPIs/I4.0 Risks	KPI1	KPI 2	KPI 3	KPI 4	KPI 5	KPI 6	KPI 7	KPI 8	KPI 9	KPI 10
Economic Risks A1	3.667	3.667	2.333	3.333	2.667	4.333	2.667	3	3.333	4.333
Technological Risks A2	3.333	2.667	2.333	4.333	3	3	1.667	4.333	3.333	3
Legal and Political Risks A3	3	2.667	3.333	3	3.333	2.667	3.333	2.666	3.333	4
Environmental Risks A4	3	3	2.333	2.333	3.333	4.333	2	2.333	2.333	3.667
Social Risks A5	2.667	4.333	4.667	3.667	3.333	3.667	4.667	4.333	3	4.667

Table 5.7: The Criteria Weights Obtained by the CRITIC Method

KPIs	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9	KPI10
Weights	0.1006	0.1212	0.111	0.0673	0.1276	0.0937	0.1085	0.0898	0.0888	0.0916

Table 5.8: Ranks Obtained by MABAC, PROMEETHEE II, MOORA, and COPRAS

Method	I4.0 Risks					
	Performance measure	Economic Risks A1	Technological Risk A2	Legal and Political Risks A3	Environmental Risk A4	Social Risks A5
MABAC	Criteria function (S_i)	-0.0357	0.19967	0.06133	-0.1154	0.13908
	Rank	4	1	3	5	2
PROMEETHEE II	Outranking flow $(\phi(a))$	-0.0855	0.14987	0.01153	-0.1564	0.08053
	Rank	4	1	3	5	2
MOORA	Y_i values	0.16824	0.22252	0.17544	0.14791	0.20055
	Rank	4	1	3	5	2
COPRAS	Quantitative Utility (U_i)	86.3304	100	87.5609	82.1134	94.7345
	Rank	4	1	3	5	2

5.6 Results and Discussions

This study aims to prioritize the derived I4.0 risks in agreement with the significant I4.0 KPIs, following identifying the significant I4.0 risks and KPIs. According to this research work, the prospects for the I4A radical shift that offers Indian manufacturing organizations a sustained strategic advantage will increase. The outcome of DEMATEL method's critical examination of all the KPIs used in the study is presented in **Table 5.5.** The KPIs cause the changes placed in the cause section, and the results are caused by the KPIs listed in the effect group. The sequence KPI1> KPI4> KPI8> KPI2> KPI5> KPI 10> KPI7> KPI3> KPI6> KPI9 effectively demonstrates the level of importance of the selected KPI, as determined by values in the column (R_i+C_j). Similarly, the values in the column R_i-C_j are used to classify the cause and effects. The highest positive value in the column R_i-C_j =0.9999 belonging to the KPI information security (KPI1) presents the first claim on the top position in the list of causes, followed by quality (KPI4), integrity (KPI2), interoperability (KPI8), availability (KPI3). Similarly, cost (KPI10) has the lowest (highest negative) value in the column R_i-C_j =-1.1746, thereby leading the effect list, followed by design (KPI6), flexibility (KPI9), IT infrastructure (KPI7), performance (KPI5) based on (R_i-C_j) values. The overall mapping shows that the KPI, information security (KPI1), affects every other KPI, and cost (KPI10) has been impacted by all. This finding confirms that information security (KPI1) is the most critical cause and cost (KPI 10) is the most important effect. Hence both KPIs need to be attended to with utmost urgency. The study reveals that one of the most important KPIs for mitigating risk-related concerns and successfully implementing I4.0 practices is information security (KPI1), as stated through the standards and processes of data gathering, processing, CC and data analytics, sensors, and IoT devices. A necessary component of I4A is the cost-efficient, adaptable, high-performing infrastructure that offers seamless internet access to serve top decision-makers in real-time.

Another problem is producing, capturing, storing, and making data accessible for real-time decision-making purposes (human or machine) without compromising the essence of information security (Ali et al., 2021; Culot et al., 2019; Khan and Turowski, 2016a). The massive amounts of data and information generated as a result of connecting IoT devices, communication, networking, man-machine integration, and collaboration among them, as well as end-to-end, vertical, and horizontal integration of the virtual and physical worlds, are extremely susceptible to jeopardy all through the manufacturing process (Kiel et al., 2017; Nara et al., 2021; Santos et al., 2017). This study's findings assert that quality (KPI 4) and customization are primary concerns when concentrating on the I4.0's economic standpoint (Hossain and Muhammad, 2016; Tripathi and De, 2019). The key barriers concern integrity and interoperability (KPIs 2 and 8), which necessitates a protocol, standardized platform, and communication network to interact with internal business processes and external suppliers, affecting the system's quality (Gökalp et al., 2017). A secure network, data privacy issues, and confidence in information sharing among the system's peripherals that contribute to the integrity (KPI2) are extremely important because the majority of risks in industrial applications arise from data integrity loss, information security, and cyber-attacks (Dubey et al., 2020). As a result, the determined cause KPIs impacting the effect KPIs offer the critical insights that establish their necessity in the risks management model of the I4.0 transformation, which makes this study unique. At the same time, companies are precluded from taking the risk of fully implementing I4.0 due to the significant investment needed to transform the current setup into a progressive and aligned to the I4.0 structure. This requires innovative technology infrastructure, a service-based business model infused with information security, and a customer-centric approach with uncertain profitability, confirming the cost concern is an important I4.0 KPI, thus endorsing the assertions by Terra et al. (2021) and Morgan et al. (2021). Also, the production system's limited resources and less automated but more flexible processes impede the I4.0 transformation's success. Hence, a significant investment is required to improve the supporting infrastructure to achieve the highest standards of information safety, network security, device connectivity, and human skills through the best use of resources (Müller et al., 2018b). Therefore, this study is an extension of earlier research that shows cost and information security concerns are crucial KPIs to consider when evaluating risks and overcoming implementation challenges for I4.0, and must be considered urgently to move toward I4A.

As reflected in **Figure 5.3**, the KPIs combinations as KPI 1- KPI 2, KPI 1- KPI 4, KPI 1- KPI 5, KPI 1- KPI 8, KPI 2- KPI 4, KPI 2- KPI 5, KPI 2- KPI 8, KPI 3- KPI 8, KPI 4- KPI 5, KPI 4- KPI 8, KPI 5- KPI 7, KPI 5- KPI 8, KPI 8- KPI 7, has a two-way relationship, i.e., influencing each other. As a result, the digraph helps to understand the KPIs' significance and visualize their contextual interaction and mutual influence.

The ranking obtained from the four MCDM methods, namely MABAC, PROMEETHEE II, MOORA, and COPRAS, is illustrated in **Table 5.8.** The Spearman's correlation coefficient, i.e., 1 of four methods, signifies that all the four methods mentioned above are agreeable in all the obtained ranks of alternatives (I4.0 risks). This confirms the findings are correct and validated for the problem under consideration. Another finding in **Table 5.8** is that technological risks (A2) have maintained a top ranking in all the methods leaving no doubt to believe that it is the most important among all the risks under consideration. This also reflects that the technological risks and social risks are the most impacting on the I4.0 vision.

A strong technological infrastructure is required to address issues with data security, cyber-attacks, interconnection among linked devices like machines, sensors, and storage devices, and the ability to make real-time decisions across the whole value chain owing to digitalization (Kamble et al., 2018a). Hence, to enable a business model compliant with I4.0, it is necessary to modify, update, and enhance the current technological infrastructure. Even if the investment in new technological infrastructure is successful, how to dispose of the resources already in use is still a major challenge. Another challenge is the need for human and machine interaction, collaboration, and interconnection across all corporate operations. This is necessary to realize I4.0's immense potential but adds complexity, risk, and significant expense (Bonilla et al., 2018). In light of the fierce market competition, manufacturers are prevented from embracing I4.0 with full enthusiasm by issues related to data security and transparency raised by internet-based technologies and online platforms (Luthra et al., 2020). Emerging technologies like IoT, AR/VR, AI, and vertical and horizontal value chain integration have transformed the traditional company model into an emerging world corporate setting while including controlled information security measures. This will aid further in self-triggered, self-optimized, and self-configured decision-making systems adopting the technologies like autonomous robots, big data analytics, additive manufacturing, cloud computing, and cybersecurity. Hence the practitioners and managers who have a thorough understanding of these technologies will be better able to integrate them into their plans and strategies. The standardization of the man-machine, process, product, customer, CPS, and production architecture to thrive in dynamic, turbulent, and highly complicated market situations where service and product personalization is on the ascent is a major technological challenge in implementing I4.0. Thus, this supports the earlier studies' assertions and findings that technological risks should be accorded serious attention.

Even though social risks (A5) ranked second, it is also important. As opposition to adopting a new paradigm of organizational change toward I4.0 will impede the successful implementation of I4.0, the social risks component of I4.0 should receive significant attention. However, management of human resources and a people-centric strategy are still important considerations. Organizations need to have balanced and forward-thinking human resource policies that are focused on employees' work-life balance, personal growth, and a respectful, empowering, and productive atmosphere that will motivate them to offer their best. Thus, to foster a sense of ownership and belongingness among the employees, it is important to take good care of the people developing and implementing technological solutions. Numerous elements, including cost-benefit analysis, innovation, the availability of a skilled workforce, the working environment, and customer demand, influence the automation of processes and operations. Therefore, repetitious and unimaginative tasks will have the highest likelihood of becoming automated. Such positions are present in every hierarchy. Automated devices are anticipated to replace even managerial duties like planning and decision-making in production processes. It doesn't imply that the businesses won't function in the gloom. Employees will continue to be essential to the system; the only thing that might alter is the scope of their responsibilities, which a diversity of IT skills could guide sets to manage standalone, self-supporting, and integrated systems effectively (Romero et al., 2020). In workplaces where I4A is in progress, this idea also has a downside that causes employees to worry about losing their jobs, becoming obsolete, or becoming incompatible. A scenario like this demands attentive care and dedication.

Organizational structure and leadership will undoubtedly change as business models include cutting-edge technologies and shrewd business strategies, moving from a conventional approach to a fast-changing digital one. Here, the mature, adaptable, strong, and supportive IT infrastructure will open a plethora of opportunities to project teams made up of programmers, software professionals, data scientists, and core technology experts. This will create new, more flexible, dependable, quick, cost-effective, and high-quality approaches to business functions. The adverse effects put the stakeholders under immense pressure to satisfy consumer demand. Hence, to overcome these disadvantages, industries will need to expand their capacity and capability in employee training and development to keep workers up-to-date and compatible with job demands. This critical company function could be overburdened by subcontracting, which would also be detrimental to the resources' productivity and production (Birkel et al., 2019). As it may attract significant uncertain investments, it might even disrupt finance management.

A clear and well-considered change management approach will address the concerns sympathetically without scaring and stressing employees regarding the changing working habits, loss of jobs, and compatibility to new job requirements without sacrificing the organizational objectives could be a real eye-opener. If the current wave of digital transition is in line with people's objectives, it may transform employees' perspectives and help them successfully meet the obstacles of the change (Leonhardt and Wiedemann, 2015). The future employees must be mentored, instructed, and coached to build the new skills and competencies essential to manage information insights, deep learning, artificial intelligence, machine learning, data and cybersecurity challenges, IoT devices, etc. The improvement of staff qualifications through training and acceptance by them is a major challenge. The social risks are also influenced by a different societal attitude on privacy rights, data protection, surveillance, and security issues of RFID and IoT devices, data uses, cloud services, and agreements of data sharing with employees and businesses, i.e., dependable users. A conversational approach to making crucial decisions is always more likely to be successful. Other important factors in gaining the trust and confidence of the workforce in the system are visibility and a trustworthy workplace culture concerning the personal and work-related information management policies using end-to-end encrypted services. Thus, this study's outcomes reinforce and empirically validate the findings of the previous studies that the technological and social risks must be attended on the top priority while moving forward to the I4A vision. Companies will eventually have to adopt I4.0 as the new norm. Those who disagree will enhance their chances of being eliminated from the competition. It will either be embraced voluntarily or forcefully.

The above finding obtained through four identified MCDM methods is validated through sensitivity analysis to assure the robustness of the derived solution. The results of the sensitivity analysis are presented below. The results of the sensitivity analysis study on the impact of dynamic decision matrices on rank reversal are shown in **Table 5.9 and Figure 5.5**. The MABAC approach (a) is not substantially agreeable with the other three methods (b,c,d), whereas these three methods achieved the same performance. The alternatives in ranks 5,4, and 1 hold the position consistently. The MABAC method shows the rank reversal in the position of alternatives like ecological risks(A3) and social risks (A5) in dynamic decision matrices at S2 and S3. At the same time, the position of the best alternative, technological risks (A2), remains at its top position in all dynamic decision matrices. The other three methods, PROMETHEE II, MOORA, and COPRAS, as shown in **Figure 5.5,** have given the same outcome. Hence, they seem to agree with each other by maintaining the same ranking in all dynamic decision matrices. This proves the robustness of the accuracy of the ranking of the alternatives under the dynamic decision-making environment. The above analysis confirms the credibility of the proposed model and can strongly be recommended for I4.0 risks prioritizing the problem.

Again, one more method is applied for sensitivity analysis to ensure the credibility of the proposed model. The sensitivity analysis compared the ranking obtained using six sets of KPIs, as shown in **Table 5.10.** The random tests conducted in this analysis, as shown in **Table 5.11**, provide nearly identical ranking performance of risk alternatives, demonstrating the consistency of all ways to address the issue of ranking risk alternatives for I4.0 implementation. While **Table 5.12** shows, Spearman's ranking correlation coefficient and Kendall's coefficient of concordance show a very strong agreement with the base ranking of risk alternatives by the MABAC method. PROMETHEE II, MOORA, and COPRAS also significantly complement MABAC. It assured the researcher that the MCDM methods chosen to address the present issue considered in this study is essential.

Therefore, this study is a pioneer in evaluating a broad range of I4.0 KPIs and offers a novel contribution to the field. It attempted to address as several potential I4.0 KPIs as possible that were either unaddressed or only partly considered in previous studies.

Table 5.9: Effect of Dynamic Decision Matrices on Rank Reversal

MABAC				
	S1	S2	S3	S4
A1	4	4	X	X
A2	1	1	1	1
A3	3	3	2	2
A4	5	X	X	X
A5	2	2	3	X

PROMETHEE II				
	S1	S2	S3	S4
A1	4	4	X	X
A2	1	1	1	1
A3	3	3	3	X
A4	5	X	X	X
A5	2	2	2	2

MOORA				
	S1	S2	S3	S4
A1	4	4	X	X
A2	1	1	1	1
A3	3	3	3	X
A4	5	X	X	X
A5	2	2	2	2

COPRAS				
	S1	S2	S3	S4
A1	4	4	X	X
A2	1	1	1	1
A3	3	3	3	X
A4	5	X	X	X
A5	2	2	2	2

Another significant addition of the present study is to expand it further to evaluate the sustained I4.0 deployment risks, which were left unaddressed in earlier studies. The study's inferences are firmly supported by data and validated by earlier research, which has established the legitimacy of the derived model used in the present study. Further, the study implications have elaborated ahead in this section.

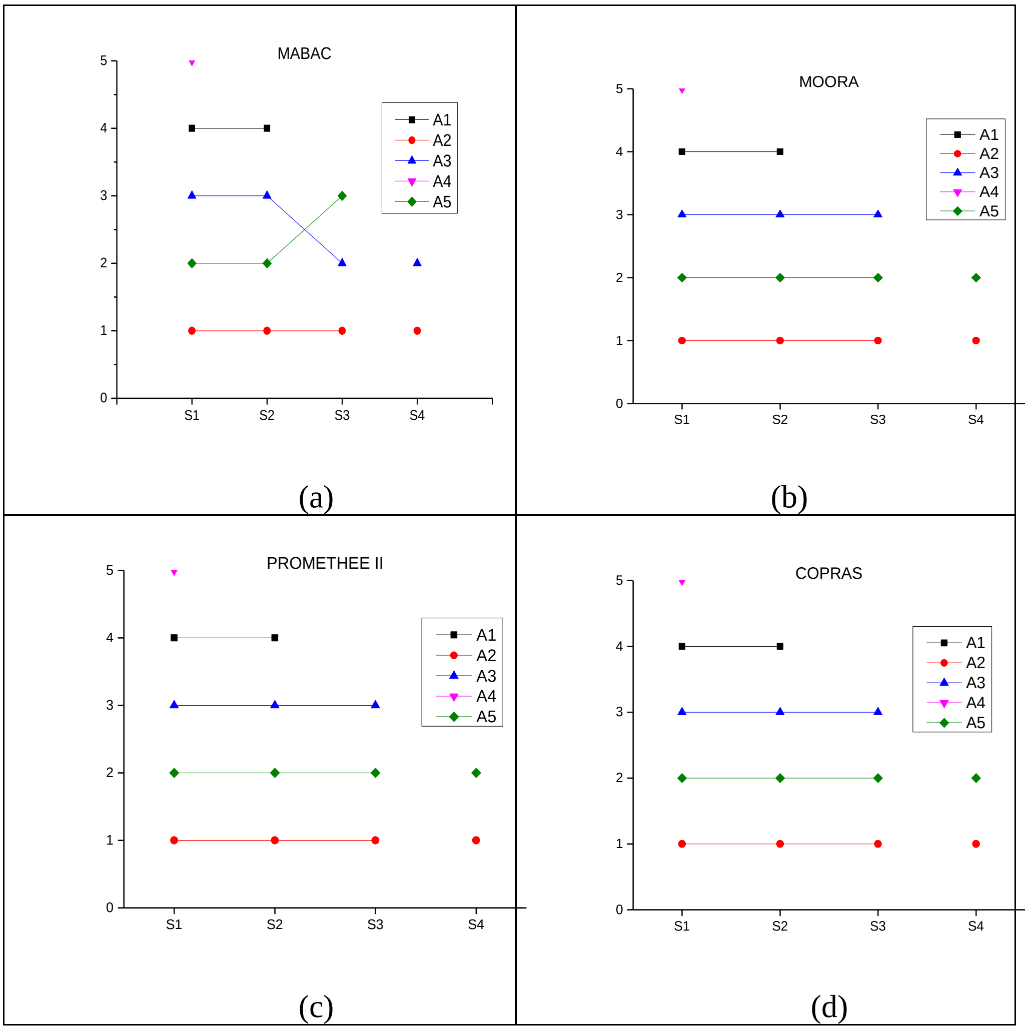

Figure 5.5: Comparison of Rank Reversal obtained by MABAC (a), PROMEETHEE II (b), MOORA(c), and COPRAS(d)

Table 5.10: Six Tests for the Sensitivity Analysis of MABAC, PROMETHEE II, MOORA and COPRAS Method

Test/ KPIs weights.	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	W_9	W_{10}
T1	0.1305	0.0222	0.1060	0.1022	0.1164	0.2957	0.0925	0.0487	0.0378	0.0481
T2	0.1164	0.1060	0.1022	0.1305	0.0487	0.0378	0.0222	0.0925	0.2957	0.0481
T3	0.1305	0.1060	0.1164	0.1022	0.0925	0.0378	0.0222	0.0481	0.2957	0.0487
T4	0.0925	0.1305	0.0481	0.2957	0.1164	0.0378	0.0487	0.1060	0.1022	0.0222
T5	0.1022	0.1164	0.1060	0.0481	0.0378	0.1305	0.0487	0.0925	0.2957	0.0222
T6	0.0378	0.1164	0.1022	0.1060	0.0222	0.0481	0.0487	0.2957	0.1305	0.0925

Table 5.11: Result of Sensitivity Analysis in Each Test for MABAC, PROMETHEE II, MOORA, and COPRAS Method

MABAC

	Base Rank	T1	T2	T3	T4	T5	T6
A1	4	4	3	4	3	4	3
A2	1	1	1	1	1	1	1
A3	3	2	4	3	4	3	4
A4	5	5	5	5	5	5	5
A5	2	3	2	2	2	2	2

PROMETHEE II

	Base Rank	T1	T2	T3	T4	T5	T6
A1	4	4	2	4	3	4	3
A2	1	1	1	1	1	1	1
A3	3	2	4	3	4	2	4
A4	5	5	5	5	5	5	5
A5	2	3	3	2	2	3	2

MOORA

	Base Rank	T1	T2	T3	T4	T5	T6
A1	4	4	3	3	3	4	3
A2	1	1	2	2	1	1	1
A3	3	2	4	4	4	3	4
A4	5	5	5	5	5	5	5
A5	2	3	1	1	2	2	2

COPRAS

	Base Rank	T1	T2	T3	T4	T5	T6
A1	4	4	3	3	3	4	3
A2	1	1	2	2	1	1	1
A3	3	2	4	4	4	3	4
A4	5	5	5	5	5	5	5
A5	2	3	1	1	2	2	2

Table 5.12: The Performance Test Result of Four MCDM Methods

Method	**Base Ranking**	**Correlation Method**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
MABAC	Base Ranking	Spearman's correlation	0.9	0.9	1	0.9	1	0.9
		Kendall coefficient of concordance	0.8	0.8	1	0.8	1	0.8
PROMETHEE II	Base Ranking	Spearman's correlation	0.9	0.7	1	0.9	0.9	0.9
		Kendall coefficient of concordance	0.8	0.6	1	0.8	0.8	0.8
MOORA	Base Ranking	Spearman's correlation	0.9	0.8	0.8	0.9	1	0.9
		Kendall coefficient of concordance	0.8	0.6	0.6	0.8	1	0.8
COPRAS	Base Ranking	Spearman's correlation	0.9	0.8	0.8	0.9	1	0.9
		Kendall coefficient of concordance	0.8	0.6	0.6	0.8	1	0.8

5.6.1 The Implication to the Managers and Policymakers

Numerous insightful conclusions have been developed as a result of this methodical and critical research of the I4.0 risks and I4.0 KPIs, providing value to decision-making. When developing the I4.0 implementation strategies and policies, the division the KPIs into two groups—cause and effect—brings additional clarity. The study has also shown how important it is for KPIs to be related to one another, which may be particularly interesting to management, bureaucrats, consultants, and other stakeholders as they work to make I4A a success. One of the main outputs of this research is the categorization of the KPIs into cause-and-effect categories by the observation of visual and contextual interrelationship digraph. This will help decision-makers accelerate the deployment of I4.0 by focusing on the KPIs that have the greatest influence and impact. Additionally, this will serve as a foundation for planning and developing the foundation and policies for reducing the risks associated with the implementation of I4.0. According to findings, professionals ought to concentrate more on the acknowledged causes (KPI1, KPI4, KPI2, KPI8, KPI3), the most important prominence KPIs being information security (KPI1), quality (KPI4) and receiver KPI cost (KPI4). Planning and managing these cause KPIs properly will help the practitioners to reduce the cost (KPI10) and improvement in design (KPI6) of the I4.0 compliant system in an effective manner. While imbibing flexibility (KPI9) and investment in infrastructure (KPI7) and performance (KPI5) will help mitigate the I4.0 risks.

According to the research, professionals should improve their skills and capacities by adopting I4.0 standards and raising their level of understanding of technological difficulties and risk-related problems brought on by threats to information security. When choosing third-party service providers to host and operationalize firm data, managers should exercise caution. Increased focus on KPI1 and KPI4 will increase confidence in the reliability of the information sources. By obtaining and exchanging real-time data across the whole value chain, professionals will feel more confident about implementing I4.0 techniques. Consequently, a powerful, reliable, and secure technology platform is needed to adequately address KPI1 and KPI4. Wireless IoT devices using a public network are more vulnerable to information security breaches. As a result, end-to-end encryption should be used for data sharing and transmission. In this situation, cloud computing will prevent unwanted and unverified access and guarantee smooth data security, data analytics, data management, cloud computing, and availability as and when necessary (Bhuiyan et al., 2020). Due to limited capital investment options, a lot of businesses subcontract production and manufacturing services (Prinsloo et al., 2019). Policymakers must immediately focus on developing secure and safe cloud-based systems in light of this. The study's established KPIs will give stakeholders a platform and a mechanism to keep track of, assess, manage, and analyze risks as they embrace I4.0 policies. The scalability of the integrated model includes small, medium, micro, and large-scale businesses.

Additionally, it looks after the I4.0 setup's quality, information security, and social sustainability. For emerging nations like India to have high decision-making precision and accuracy, policymakers must be stress-free while also being careful, watchful, and imaginative. Evaluating the resource's overall effective use is crucial, but the cost component should be considered a significant element. The finding obtained through MABAC, PROMEETHEE II, MOORA, and COPRAS methodology, technological risks, and social risks are the critical concern while implementing the I4.0. Therefore, policymakers should specify the sustainable goals for choosing the proper I4.0 technology to develop smart processes and products (Machado et al., 2019; Parhi et al., 2021). The conventional management framework is being redefined by emerging technologies like AR, VR, ML, AI, CPS, IoT, horizontal and vertical integration, digital twins and autonomous and conscious decision-making mechanisms. The further amalgamation of 3-d printing, advanced robotics, big data analytics, cloud technology, and data security are also trying to alter the worldwide business setting. By prioritizing technological risks, practitioners and leaders will be better able to integrate these technologies into their plans and strategies. Therefore, standardization in the products, processes, man-machine consumer and production layout is a top technological issue in I4A in order to compete in dynamic, volatile, and challenging market dynamics where product and service customization is rising. As a result, managers and practitioners must give strategic strategies for promoting technological improvements in enterprises their undivided focus. Every business needs its employees as one of its most important resources. Managers can succeed in I4.0 activities by encouraging a collaborative, cooperative workplace by altering their attitudes regarding opposition to implementing the new culture in the workplace, technical skills, and attitude toward change. In line with the study findings on the priority of social risks for I4.0, the transition will guide the managers to convince and motivate the workforce by creating awareness. I4.0-specific skill sets and capabilities, such as IT infrastructure management, BDA, and human-machine interface management, software, hardware handling, are addressed through designing employee training and development opportunities (Arnold and Kiel, 2016; Bologa et al., 2017). One of the methods for managing change in a firm could also involve CC, AI, the use of AR/VR technology in training, collaborative robot management, networking, and connectivity protocol handling skills. Policymakers should exercise caution in identifying organizational culture and human performance in order to address the social concerns associated with the I4A (Chiappetta Jabbour et al., 2020). The study makes recommendations for management, stakeholders, and administrators to develop comprehensive and sound long-term strategies that will ensure the success and profitability of I4.0 in the long run by reducing technological and social risks.

5.6.2 Theoretical Implications of the Study

The primary objective of this research is to determine the cause-and-effect interrelationship among the impacting KPIs on the risks of I4.0 implementation. This study contributes to the theory and literature in various aspects. The identified KPIs and risks were extracted from extensive literature compilation and relevant studies on I4.0 readiness, risks, sustainability, challenges, technology, social, legal, and political aspect, etc., and validated by experts, assuring the study's reliability. This distinctive study has explored the KPIs and risks for I4A and derived a framework using combined DEMATEL, CRITIC-MABAC, PROMEETHEE II, MOORA, and COPRAS methodology for the I4A in the Indian context. A developed digraph for KPIs evaluation and a causal diagram for KPIs will help researchers to clearly understand and categorize the KPIs for the I4.0, which will provide the basis on which the essential KPI information security and cost can be handled urgently. This will assist researchers and scholars in investigating and exploring solutions to deal with this by adopting a secured network, reliable data sharing and exchanging, authentic use of the cloud, technology end-to-end encrypted applications, etc. The prioritized risks, i.e., technological and social risks in this study, help the researchers to develop their study further for the strategic, reliable roadmap formulation for gearing up for I4A through the development of human resources to be better equipped to manage I4.0 technology. In this approach, the study has the ability to assist the government of India's digital India project and serve as the foundation for the creation of a new research model and methodology in the future, thereby advancing knowledge.

5.6.3 Study Implications in Post-COVID-19 Pandemic Scenario

It is highly deplorable that the COVID-19 pandemic has halted entire world operations without giving any alert. Although this seemed true, the disease sparked the fast-paced adoption of digital technology, resulting in the fastest technology transfer ever in the history of industrialization. To better prepare for the upcoming and unknowable challenge, it is necessary to cooperatively reimagine, rethink, re-skilling, and redesign the progress of mankind (Mckinsey, 2021). This will demonstrate how resilient manufacturing companies are. In the eventuality of a pandemic, businesses should develop crisis plans by reconfiguring and refocusing their operations to keep a competitive edge while also engaging in corporate social responsibility. To access physical assets like machines and gadgets, business organizations need to have a solid understanding of technology and digital competencies. In order to remotely collect and monitor real-time data, high-end cameras and sensors accompanied by IoT applications that integrate with AI and satellite technologies are to be used (Bai et al., 2020). It lets the operators interact with the machines remotely while requiring little physical effort, allowing for monitoring and correcting the machines' operation, effectiveness, and other factors. Modern digital transformation technologies, including 3D printing, ML, IIoT, RFID, AI, sensors, digital twins blockchain, and BDA, propels the introduction of automated manufacturing processes by making the supply chain and assembly lines visible and traceable (Widayani et al., 2020). Companies that had already completely or partially implemented these technologies were said to be comfortable handling COVID-19-enforced conditions, including lockout, confinement, social separation, and the use of masks and sanitizers. Cobots and humanoid robots may be the most effective way to work remotely because they require little human interaction, which will become the expected trend in business in the future.

Research findings were discussed with the experts selected for this study. It is observed that the results obtained are most appealing to reality, which arises due to the COVID-19 pandemic. One of the key requirements for overcoming the challenges brought on by the COVID-19 epidemic is current societal progressive thinking and an open attitude toward adopting new technology.

This study may serve as a guide for professionals, technocrats, leaders, and policymakers as they create their own implementation roadmaps for I4.0, keeping the aforementioned risks in mind as a top priority both during and after the COVID-19 epidemic.

5.7 Conclusions and Limitations

I4.0 has the capability to transform the entire industrial value chain for the better by putting the customer first. Due to limitations in technology, cost, and workforce management, not every industry may be able to digitalize its entire business at once to become I4.0 compliant. Even while it initially appears lucrative and alluring, there are a lot of difficulties and risks lurking under the shell. The overall goal of deploying I4.0 may be disturbed if the numerous risks and impacting KPIs to the risks are not identified beforehand. According to the literature review, different risks have been examined to determine how the deployment of I4.0 will affect society. However, only a small number of studies have experimentally examined the causal link between KPIs, risk implementation, and risk prioritization. This study has revealed that information security and costs out of all the KPIs need attention. While on the alternatives list, the technological and social risks have been found as the most critical risks, which must be attended urgently and confirmed through MCDM methods like MABAC, PROMEETHEE II, MOORA, and COPRAS. The study profoundly highlighted the factors affecting the risks, contributing toward I4.0 and risk prioritization to provide guidelines to the policymakers, researchers, and industrial personnel to help in the decision-making process to imbibe I4.0 practices in their companies.

Twelve experts from various domains are consulted to validate the literature review's identification of the impacting KPIs and anticipated risks for the implementation of I4.0, as mentioned in **Section 5.5.** DEMATEL methodology is utilized to establish causal dependence and relationships between the KPIs Information security (KPI1) influences other KPIs, while the other KPIs influences cost (KPI10). The overall findings and results have culminated into an integrated model DEMATEL, CRITIC-MABAC, PROMEETHEE II, MOORA, and COPRAS. The sensitivity analysis proved the proposed integrated model's robustness, which ultimately supported the model's suitability for use in practical applications. This is also verified by the experts who suggested the implementation in the companies.

Since I4.0 is still relatively new in terms of study and implementation, there isn't a single, all-encompassing roadmap or standardised guidance covering all of its aspects. This report encourages practitioners and stakeholders to adopt I4.0 wholeheartedly by making a comprehensive effort to identify risks and influence KPIs. However, as will be mentioned further, this research has several shortcomings that should be taken into account for follow-up studies. Five risks for the I4.0 have been assessed based on the ten KPIs that this study highlighted. These KPIs and risks came from the literature, and Indian specialists who are familiar with I4.0 validated them. The study may provide more substantial insights into the KPIs and types of risks affecting the implementation of I4.0 in particular states or countries if it is conducted in other industrialized countries. A similar study should be conducted in other industrialized nations that have previously adopted I4.0 in their businesses in order to uncover further aspects of how I4.0 transformation may affect KPIs and potential I4.0 risks.

The integrated DEMATEL, CRITIC-MABAC, PROMEETHEE II, MOORA, and COPRAS methodology, used subjective judgments of the industrial practitioners, academicians, and consultants. This study established linkages between the chosen KPIs and prioritized the risks with the biggest effects on I4A in the Indian setting. The personal biases of the chosen experts cannot be avoided, despite the researcher’s best efforts to eliminate them; as a result, the results may be affected. Additionally, this study advises employing an empirical research design approach and confirming the results using a survey-based methodology. Additionally, using structural equation modeling tools and other multicriteria decision-making methods may yield more precise results.

6 Development of Industry 4.0 Implementation Framework and Mathematical Model to Evaluate Sustainable Organizational Performance

6.1 Introduction

Indian manufacturing organizations are passionately pursuing the I4A. The momentum is gradually and steadily growing as companies seem to be convinced about I4.0’s opportunities (Pacchini et al., 2019). Although the speed is no match to the developed economies, the objective of the Indian companies is very positive and motivating. The slow speed might be primarily attributed to the insufficient of a unified platform and the inadequate resources available to encourage company trust in the prospects of I4.0 (Sharma et al., 2021). Today’s technological paradigm change reflects that manufacturing organizations are aggressively looking for catapulting opportunities to capitalize on I4.0 opportunities. However, the research in this area lacks sufficient empirical evidence in the extant literature on adopting I4.0 capabilities; hence this study is important.

Additionally, I4A supported by DC and CEP leading to SOP in the context of Indian organizations is unfortunately not quantified and explored. This reinforces the necessity for a framework tested thoroughly by empirical evidence, which is a key aspect of this study. This gap is filled by the present study, which emphasizes on Indian manufacturing enterprises and empirically investigates the impact of I4A on SOP, acknowledging the integrating effect of DC and CEP. This study also attempted to investigate the relationship between I4A, DC, and CEP drivers, as well as the relationship between I4A and DC, DC and CEP, and CEP and SOP, in order to solve the critical issues of scarcity or dearth of literature in developing nations like India. This study adds to the body of knowledge in a number of ways, assisting scholars, professionals, and policymakers as they continue the I4A drive.

The researcher has deployed an online survey platform, such as a Google Form, and whenever possible, paid in-person visits to the potential respondents to gather primary data using a survey-based approach (Pinsonneault and Kraemer, 1993). The link of the questionnaire created online was sent to the intended respondents via email. Social media platforms like Telegram, LinkedIn, Twitter, and WhatsApp, as well as occasional one-on-one in-person interactions, were used to reach out to some responders.

It is now very well agreeable that I4.0 knowledge and awareness are growing, but there is still a long way to go. The SLR focusing on the earlier research in this field confirms that the large potential of I4.0 is still untapped; therefore, its adoption is in the immature and transition stage. In light of this, the researcher combined the newly designed scale with the existing scale, followed by consultation with the experts (Churchill, 1979; Müller et al., 2018b) to measure the identified constructs. Only highly relevant and significant constructs (latent variables) and their associated measuring indicators have been considered in this research. These measurement items are meticulously updated, adjusted, and checked for validity, reliability, and consistency by experienced industry professionals and academicians before being approved to measure the constructs.

Finally, an online version of this comprehensive questionnaire is created and distributed to all potential responders through email, personal visits, and respective social media platforms.

The questionnaire's data was based on a five-point Likert scale, where 1 denoting strong disagreement and 5 denoting strong agreement, as demonstrated in **(Appendix 1).** The reflective scale has been used in this study to measure the selected latent variables (Diamantopoulos and Winklhofer, 2001).

The questionnaire is designed to evaluate a total of 61 indicators. The second-order latent variable I4A: three indicators were measured with six first-order latent variables (capital investments: three indicators, stakeholders as employees and customers: four indicators, organizational strategies: three indicators, smart product and operations: three indicators, I4.0 technologies: four indicators, I4.0 standards: two indicators). Other second-order latent variables DCs: four indicators measured with five first-order latent variables (digital leadership: three indicators, risks mitigation: three indicators, supply chain agility: three indicators, innovation capabilities: three indicators, employee empowerment: four indicators). CEPs: three indicators are another second-order latent variable measured with three first-order latent variables (innovation in green processes: three indicators, circular dynamic environment: three indicators, investment recovery: two indicators), and SOP measured considering eight indicators.

Before conducting the final survey, the designed questionnaire undertook a pilot test to assess and guarantee its accuracy, reliability, and content validity. The involvement of experts and statistical methods together confirmed the further inclusion and exclusion of the final indicators in the existing version of the questionnaire (Dillman, 1978). The active engagement of fifteen experts from business and academia with backgrounds in industrial engineering, production and operations management, information and communication dedicated to data and cyber security, along with professional working experience on the I4A projects, has increased the developed questionnaire's credibility and ensured its viability for the intended purposes.

To evaluate the efficacy of the created research instrument, the pilot study was conducted by distributing a survey questionnaire to 65 respondents from manufacturing companies in Maharashtra, India. The measuring indicators reflecting Cronbach alpha (α) value lower than 0.70 and showing vagueness were either discarded, modified/corrected, or reconsidered. Further, the final constructs and contributing measuring indicators culminated, as shown in **(Appendix 1).**

Thus, taking this study's purpose into account, this chapter elaborates further on survey data observations in Section 6.2, important statistics about the respondents' demographic profile in Section 6.3, an analysis of the PLS-SEM path model's outcomes in Section 6.4, and finally mathematical modeling development to generalize the results outcome in Section 6.5.

6.2 Survey Data Observations

Industries all over India were the intended population for this research work. The sample is drawn from companies located in Indian states, including Maharashtra, Uttar Pradesh, Kerala, West Bengal, Rajasthan, Gujarat, Karnataka, Tamil Nadu, Andhra Pradesh, Delhi, Haryana, Madhya Pradesh, and Punjab. The researcher ensured the participation of all size companies by reaching out to the respondents from different manufacturing industries, including large-scale, small, and medium-scale industries.

As the study was conducted during the COVID-19 pandemic, which imposed limited access to the company's premises and expected strict adherence to COVID-19 appropriate behavior, the sampling methodology used for data collection was a non-random, purposive, and snowball methodology. Using these methods, researchers have reached the most reliable and plausible respondents who represent a broader target population segment. The survey respondent's contact is collected from databases on government web portals, the websites of the organizations, the industry alliances, I4.0 professionals forums, professional network, and industry contacts. All contacts are reached out in person only when it is appropriate; otherwise, the respondents are contacted through email and social media. A carefully drafted questionnaire affirmed the respondents' participation in I4.0 initiatives. Due to the relatively lower response rates on social media and email, reminders were given after every four weeks.

It took considerably more time and effort to get the desired data due to the setback of the COVID-19 pandemic. Thus, to encourage respondents, personal visits to the plant, telephone persuasion, and Google Meet discussions were arranged as and when suitable. This cross-sectional study collected data through an online survey between January 2021 and March 2022. After sending out the questionnaire to 866 potential respondents from 570 manufacturing organizations, 297 responses were received from the targeted 866 responders, out of which 17 were either prejudiced or wrongly filled and thus omitted from the list to consider further data analysis. Thus finally, 280 complete responses were obtained, usable replies representing 225 companies, with a response rate of 32.33%. The other research in the Indian setting has likewise attained a comparable response rate, which is equally significant to note. For example, the response rates achieved in the studies of Kamble et al. (2020) and Gupta et al. (2020) were 34% and 32.29 %, respectively. Thus, as mentioned in the research carried out in India, the response rate of 32.33%, as obtained in this study, is adequate (Malhotra and Grover, 1998).

According to the earlier literature findings, the adequate sample size ranges from 89 to 4000 for applying the SEM technique, depending upon the data availability and research objectives (Oliveira and Martins, 2010). The number of constructs also correlates to the sample size as suggested by Y. Zhu et al. (2010) confirming that 65 to 133 respondents are sufficient for similar studies. Hair et al. (2014), and Kock and Hadaya (2018) also recommended that a sample size of 150–200, or ten times the number of arrows heading in the direction of the latent construct, is acceptable. Moreover, researchers validated the sample sizes from earlier studies and used the sample size calculator to propose an approximately fitting sample size in the current scenario (National Statistical Service, 2018).

The data quality is confirmed by ensuring that the respondents had first-hand knowledge and experience of I4.0 initiatives and were a part of businesses that had implemented or pilot-tested I4.0 techniques in their particular industrial environments. With this, we draw the conclusion that, when employing the SEM technique and the SmartPLS algorithm, the sample size of 280 is more than enough to perform confirmatory factor analysis. Additionally, selecting the PLS-SEM technique for this study established confidence in its choice of research tool made. Earlier studies have most frequently used this algorithm and software for the analysis and modeling based on SEM. One specialty of Smart PLS is that it produces reliable outcomes even though the data is non-normal and the sample size is small (Hair et al., 2011; Ringle et al., 2010). Nevertheless, the data obtained in this study is approximately normal; hence the use of the SmartPLS SEM application is well-endorsed. Also, it is considered the algorithm has the capacity to ascertain the complex causal relationship encompassing several paths, variables, constructs and and develop a reliable model. Similarly, since it decreases unexplained variance and raises the explained variance (R^2) value of endogenous constructs, PLS-SEM is the most preferred technique for assessing causal relationships in empirical investigations (Sarstedt and Cheah, 2019). This inspired the researcher to use PLS-SEM and accomplish the set of goals for the current investigation.

Additionally, Onwuegbuzie and Leech (2005) recommended conducting a data assessment before conducting an inferential and descriptive data analysis. Therefore, after screening and coding the data, the researcher has examined missing value assessment, outliers' assessment, common method bias, non-response bias, and descriptive statistics to ascertain whether statistical methods assumptions are met.

6.2.1 Screening and Coding of Data

Coding is an essential part of data preprocessing. All the collected data, therefore, is coded before drawing further statistical inferences. Allocation of appropriate numbers to the variables, ranges, and literary expressions is part of the coding process. This study first coded the measurement scales for the section B constructs and associated measuring indicators to support the statistical analysis. All coded measuring indicators and respective constructs are included in **(Appendix 1).** Following codification, data screening started, taking into account the typical assumptions in different statistical studies. Data screening is important in any multivariate study since it enables the researcher to uncover certain crucial beliefs that might have been ignored when using multivariate approaches to analyze data (Hair et al., 2007).

6.2.2 Missing Value Assessment

If ignored, missing values can have a negative effect on the validity of the results. This study analyzed the missing values by first understanding the trends of missing data and then making up for the losses by replacing the missing data values. If more than 50% of the responses by a single respondent are unfilled or missed, the respondent is dropped from the data set, subject to the study does not have sample size issues (Hair et al., 2013). However, this study did not have missing data issues because of the technical settings in the online Google form. Respondent had to answer all the questions, without skipping any, before submitting the form. As a result, the dataset of this study survey had no missing values.

6.2.3 Outliers Assessment

In this study, outliers were identified by using the Mahalanobis distance (D^2), which quantifies how much a data point deviates from the centroid of the remaining data points. The mean of all variable values forms the value known as the centroid. The SPSS v23 software package was used to test the outliers in each data point collected for this study. According to Hair et al. (2013), the threshold level for the indicator D^2/Df in large samples, mainly more than 100, should be lesser than 3 or 4. Using the SPSS regression method, it was identified that the collected data was free from outliers.

6.2.4 Common Method Bias

Respondents typically struggle to supply the necessary insights that the researcher needs since their bias is mostly impacted by ambiguity and a lack of knowledge about how the data acquired through the questionnaire will be used. The researcher has taken the necessary and pertinent procedures at the level of questionnaire design to prevent this misunderstanding in light of this concern. In order to maintain the entire anonymity of the respondents and related privacy and to obtain perfect, unbiased, and trustworthy data, the researcher has appropriately addressed this issue by sharing the facts about the scope, objectives, and purpose of this academic research. The researcher has obtained information from multiple respondents from the same company; thus, this issue needs to be handled appropriately. Thus, to address this Common method bias (CMB) issue, the researcher employed the SPSS v23 program to perform the most used Harman's single-factor test. The outcomes of this test are displayed in **Table 6.1,** and it shows that the first factor accounts for 36.28% of the total variation. This means the data collected does not have the CMB problem as the value obtained is far lower than the maximum criterion limit of 50% (Podsakoff et al., 2003).

Table 6.1: Harman's Single-Factor Test – Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	22.132	36.282	36.282	22.132	36.282	36.282
2	4.611	7.56	43.841			
3	4.37	7.164	51.005			
4	2.529	4.146	55.151			
5	2.418	3.965	59.115			
6	1.8	2.951	62.067			
7	1.765	2.893	64.959			
8	1.399	2.293	67.253			
9	1.361	2.232	69.485			
10	1.226	2.01	71.495			
11	1.128	1.848	73.343			
12	0.984	1.612	74.956			
13	0.974	1.596	76.552			
14	0.845	1.385	77.937			
15	0.81	1.328	79.265			
16	0.784	1.286	80.551			
17	0.758	1.242	81.793			
18	0.707	1.159	82.952			
19	0.69	1.131	84.083			
20	0.633	1.037	85.121			
21	0.621	1.019	86.139			
22	0.554	0.909	87.048			
23	0.549	0.9	87.948			
24	0.531	0.871	88.819			
25	0.478	0.784	89.603			
26	0.466	0.765	90.368			
27	0.446	0.73	91.099			
28	0.432	0.708	91.807			
29	0.421	0.69	92.496			
30	0.378	0.62	93.117			
31	0.356	0.584	93.7			
32	0.331	0.543	94.243			

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
33	0.31	0.509	94.752			
34	0.306	0.501	95.253			
35	0.281	0.461	95.714			
36	0.269	0.441	96.155			
37	0.248	0.406	96.561			
38	0.226	0.37	96.931			
39	0.223	0.365	97.296			
40	0.199	0.327	97.623			
41	0.185	0.303	97.926			
42	0.176	0.289	98.215			
43	0.156	0.257	98.471			
44	0.147	0.24	98.712			
45	0.14	0.229	98.94			
46	0.127	0.208	99.148			
47	0.106	0.174	99.322			
48	0.093	0.153	99.475			
49	0.074	0.122	99.596			
50	0.068	0.112	99.708			
51	0.065	0.107	99.815			
52	0.056	0.093	99.908			
53	0.031	0.051	99.958			
54	0.025	0.042	100			
55	0.000115	0.000189	100			
56	0.000053	0.000869	100			
57	0.000282	0.000462	100			
58	0.00023	0.000377	100			
59	0.0004009	0.000657	100			
60	0.0005603	0.000918	100			
61	0.0001056	0.000173	100			
Extraction Method: Principal Component Analysis.						

6.2.5 Non-Response Bias

Non-response bias method is used to establish the broad application of the findings. In this study, the researcher used the non-response bias to confirm the generalizability of the findings using paired samples t-test. The non-response bias test is widely used in survey-based studies to confirm that there is no difference in the responses received in the early and later stages of the research. To determine whether there is any substantial difference between the early and late respondents' replies received for the questionnaire, the non-response bias test is preferred. The test analyzed two groups of early 30% (n=84) and the last 30% (n=84) cases from the total 280 cases to reduce the chances of information bias. Further, the difference between these two groups was calculated using paired sample t-test (Armstrong and Overton, 1977). The findings demonstrated that there is no non-response bias problem with a 95% confidence level. There was no significant statistical difference observed between the two groups, as shown in **Table** 6.2**.**

Table 6.2: Paired Samples T-Test for Non-Response Bias

		Paired Differences							
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	I4A1_E - I4A1_L	.037	.901	.100	-.162	.236	.370	80	.712
Pair 2	I4A2_E - I4A2_L	.086	.897	.100	-.112	.285	.867	80	.389
Pair 3	I4A3_E - I4A3_L	.086	.938	.104	-.121	.294	.829	80	.409
Pair 4	I4ACI1_E - I4ACI1_L	.062	1.004	.112	-.160	.284	.553	80	.582
Pair 5	I4ACI2_E - I4ACI2_L	-.012	.887	.099	-.209	.184	-.125	80	.901
Pair 6	I4ACI3_E - I4ACI3_L	-.074	1.034	.115	-.303	.155	-.645	80	.521
Pair 7	I4ASEC1_E - I4ASEC1_L	.086	1.434	.159	-.231	.403	.543	80	.589
Pair 8	I4ASEC2_E - I4ASEC2_L	-.049	1.350	.150	-.348	.249	-.329	80	.743
Pair 9	I4ASEC3_E - I4ASEC3_L	-.099	1.428	.159	-.415	.217	-.622	80	.535
Pair 10	I4ASEC4_E - I4ASEC4_L	-.136	1.349	.150	-.434	.162	-.906	80	.368
Pair 11	I4AOS1_E - I4AOS1_L	0.000	.806	.090	-.178	.178	0.000	80	1.000
Pair 12	I4AOS2_E - I4AOS2_L	-.025	.908	.101	-.225	.176	-.245	80	.807
Pair 13	I4AOS3_E - I4AOS3_L	-.025	.806	.090	-.203	.153	-.276	80	.783
Pair 14	I4ASPO1_E - I4ASPO1_L	-.247	.814	.090	-.427	-.067	-2.729	80	.120
Pair 15	I4ASPO2_E - I4ASPO2_L	-.123	.797	.089	-.300	.053	-1.395	80	.167
Pair 16	I4ASPO3_E - I4ASPO3_L	-.111	.837	.093	-.296	.074	-1.195	80	.236
Pair 17	I4AI4T1_E - I4AI4T1_L	.173	1.439	.160	-.145	.491	1.081	80	.283
Pair 18	I4AI4T2_E - I4AI4T2_L	.136	1.481	.165	-.192	.463	.825	80	.412
Pair 19	I4AI4T3_E - I4AI4T3_L	.148	1.629	.181	-.212	.508	.819	80	.415
Pair 20	I4AI4T4_E - I4AI4T4_L	.049	1.524	.169	-.288	.386	.292	80	.771
Pair 21	I4AI4S1_E - I4AI4S1_L	.333	1.304	.145	.045	.622	2.301	80	.140
Pair 22	I4AI4S2_E - I4AI4S2_L	.358	1.434	.159	.041	.675	2.246	80	.156
Pair 23	DC1_E - DC1_L	-.012	1.078	.120	-.251	.226	-.103	80	.918
Pair 24	DC2_E - DC2_L	.012	.942	.105	-.196	.221	.118	80	.906
Pair 25	DC3_E - DC3_L	-.025	.908	.101	-.225	.176	-.245	80	.807
Pair 26	DC4_E - DC4_L	-.074	1.010	.112	-.297	.149	-.660	80	.511
Pair 27	DCDL1_E - DCDL1_L	.272	1.369	.152	-.031	.574	1.785	80	.078
Pair 28	DCDL2_E - DCDL2_L	.173	1.430	.159	-.143	.489	1.088	80	.280
Pair 29	DCDL3_E - DCDL3_L	.383	1.271	.141	.102	.664	2.711	80	.182
Pair 30	DCRM1_E - DCRM1_L	-.235	.810	.090	-.414	-.055	-2.605	80	.124
Pair 31	DCRM2_E - DCRM2_L	-.123	.812	.090	-.303	.056	-1.368	80	.175

		Paired Differences							
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper	t	df	Sig. (2-tailed)
Pair 32	DCRM3_E - DCRM3_L	-.123	.842	.094	-.310	.063	-1.319	80	.191
Pair 33	DCSCA1_E - DCSCA1_L	.173	1.395	.155	-.136	.481	1.115	80	.268
Pair 34	DCSCA2_E - DCSCA2_L	.136	1.403	.156	-.174	.446	.871	80	.386
Pair 35	DCSCA3_E - DCSCA3_L	.173	1.282	.142	-.111	.456	1.213	80	.229
Pair 36	DCIC1_E - DCIC1_L	-.198	1.279	.142	-.480	.085	-1.390	80	.168
Pair 37	DCIC2_E - DCIC2_L	.012	1.470	.163	-.313	.337	.076	80	.940
Pair 38	DCIC3_E - DCIC3_L	-.062	1.528	.170	-.400	.276	-.364	80	.717
Pair 39	DCEE1_E - DCEE1_L	-.235	1.297	.144	-.521	.052	-1.628	80	.107
Pair 40	DCEE2_E - DCEE2_L	-.074	1.385	.154	-.380	.232	-.481	80	.632
Pair 41	DCEE3_E - DCEE3_L	-.210	1.115	.124	-.456	.037	-1.694	80	.094
Pair 42	DCEE4_E - DCEE4_L	-.136	1.243	.138	-.411	.139	-.984	80	.328
Pair 43	CEP1_E - CEP1_L	.148	1.026	.114	-.079	.375	1.299	80	.198
Pair 44	CEP2_E - CEP2_L	.099	1.056	.117	-.135	.332	.842	80	.402
Pair 45	CEP3_E - CEP3_L	-.049	1.083	.120	-.289	.190	-.410	80	.683
Pair 46	CEPIGP1_E - CEPIGP1_L	.062	1.208	.134	-.205	.329	.460	80	.647
Pair 47	CEPIGP2_E - CEPIGP2_L	.062	1.065	.118	-.174	.297	.522	80	.603
Pair 48	CEPIGP3_E - CEPIGP3_L	-.049	1.083	.120	-.289	.190	-.410	80	.683
Pair 49	CEPCDE1_E - CEPCDE1_L	.173	1.395	.155	-.136	.481	1.115	80	.268
Pair 50	CEPCDE2_E - CEPCDE2_L	.136	1.403	.156	-.174	.446	.871	80	.386
Pair 51	CEPCDE3_E - CEPCDE3_L	.173	1.282	.142	-.111	.456	1.213	80	.229
Pair 52	CEPIR1_E - CEPIR1_L	.136	1.081	.120	-.103	.375	1.131	80	.262
Pair 53	CEPIR2_E - CEPIR2_L	-.012	1.101	.122	-.256	.231	-.101	80	.920
Pair 54	SOP1_E - SOP1_L	0.000	1.072	.119	-.237	.237	0.000	80	1.000
Pair 55	SOP2_E - SOP2_L	.111	1.049	.117	-.121	.343	.953	80	.343
Pair 56	SOP3_E - SOP3_L	.148	1.026	.114	-.079	.375	1.299	80	.198
Pair 57	SOP4_E - SOP4_L	.099	1.056	.117	-.135	.332	.842	80	.402
Pair 58	SOP5_E - SOP5_L	-.049	1.083	.120	-.289	.190	-.410	80	.683
Pair 59	SOP6_E - SOP6_L	-.049	1.083	.120	-.289	.190	-.410	80	.683
Pair 60	SOP7_E - SOP7_L	0.000	1.061	.118	-.235	.235	0.000	80	1.000
Pair 61	SOP8_E - SOP8_L	.037	1.006	.112	-.185	.259	.331	80	.741

6.2.6 Descriptive Statistics

Descriptive Statistics serve as the foundation for almost all quantitative studies. It is essential to know the characteristics of the collected data before embarking on analysis. Descriptive statistics analysis is beneficial for characterizing the general features of samples, such as demographic analysis, frequency distribution, standard deviation, percentage, range, mean, skewness, and kurtosis (Onwuegbuzie and Leech, 2005). In this study, the standard deviation, mean, skewness, and kurtosis are calculated as part of the descriptive statistical analysis to better understand the nature of the surveyed data. Thus, this would further aid in assessing the current position of Indian manufacturing industries' adoption of I4.0, DC CEP, and their combined impact on SOP. Well-directed organizational policies to achieve SOP will also help enhance companies' competitiveness.

6.2.6.1 Normality Test

Normality tests are used in statistics to examine whether a data set follows a normal distribution and ascertain if sample data were taken from a normally distributed population. Several tests can be used to determine normality in the dataset. These tests presuppose that some study variables at least somewhat follow the normality criterion. A graphical presentation of the frequency distribution, which resembles a bell-shaped curve with most respondents falling between the mid-range and high ranges, and fewer respondents falling between the low and high ranges, can be used to ascertain normality. The metrics of how closely the data set resembles normalities are skewness and kurtosis. Hair et al. (2013) and George and Mallery (2009) proposed that a variable's distribution should be considered nearly normal when the skewness value is less than ±1 and the kurtosis value is ±2. In this study, the majority of the skewness values of the item are between -1 and +1 or close to 0, and the kurtosis values are distributed in the range of -2 to +2. Thus, the outcome of the normality test conducted in this study shows that the primary survey's items are approximately normally distributed and meet the requirements of the statistical test used in this study. The maximum skewness and kurtosis values were 0.983 and 1.923, respectively, which are below the acceptable limits of 1 and 2, respectively. The value of skewness and kurtosis is shown in **Table 6.3.**

Table 6.3: Descriptive Statistics of Measuring Indicators of Main Constructs and Sub- Constructs

Main Constructs/ Subconstructs	**Code**	**Mean**	**Std. Deviation**	**Kurtosis**	**Skewness**
Industry 4.0 Adoption (I4A)	I4A1	3.553	0.6	1.866	-0.854
	I4A2	3.46	0.613	1.128	-0.457
	I4A3	3.39	0.719	1.574	-0.817
Capital Investment (CI)	I4ACI1	4.033	0.659	1.328	-0.794
	I4ACI2	4.226	0.635	0.23	-0.577
	I4ACI3	4.238	0.689	-0.589	-0.419

Main Constructs/ Subconstructs	Code	Mean	Std. Deviation	Kurtosis	Skewness
Stakeholders as Employees and Customers (SEC)	I4ASEC1	4.084	0.92	0.986	-0.983
	I4ASEC2	4.073	0.919	0.563	-0.887
	I4ASEC3	4.022	0.922	0.608	-0.891
	I4ASEC4	4.073	0.911	1.097	-0.923
Organizational Strategies (OS)	I4AOS1	3.648	0.562	1.923	-0.896
	I4AOS2	4.024	0.623	0.481	-0.888
	I4AOS3	3.978	0.533	1.034	-0.91
Smart Product and Operations (SPO)	I4ASPO1	4.106	0.593	1.105	-0.352
	I4ASPO2	4.154	0.579	0.849	-0.251
	I4ASPO3	3.945	0.6	0.087	-0.082
Industry 4.0 Technologies (I4T)	I4AI4T1	3.172	1.032	-0.887	-0.049
	I4AI4T2	3.062	0.968	-0.865	0.069
	I4AI4T3	2.927	1.021	-0.887	0.002
	I4AI4T4	3.055	1.056	-0.844	-0.129
Industry 4.0 Standards (I4S)	I4AI4S1	3.073	0.977	-0.856	0.137
	I4AI4S2	3.048	1.056	-0.837	0.017
Dynamic Capabilities (DC)	DC1	4.192	0.714	1.47	-0.904
	DC2	4.008	0.641	0.16	-0.552
	DC3	4.059	0.626	-0.658	-0.446
	DC4	4.138	0.673	-0.492	-0.398
Digital Leadership (DL)	DCDL1	3.527	0.953	-0.906	-0.181
	DCDL2	3.864	0.983	0.066	-0.794
	DCDL3	3.846	0.967	0.338	-0.858
Risks Mitigation (RM)	DCRM1	4.106	0.617	1.461	-0.54
	DCRM2	4.154	0.592	0.67	-0.268
	DCRM3	3.952	0.6	0.09	-0.084
Supply Chain Agility (SCA)	DCSCA1	4.117	0.894	1.003	-0.98
	DCSCA2	4.172	0.858	1.264	-0.89
	DCSCA3	4.161	0.858	1.599	-0.94
Innovation Capabilities (IC)	DCIC1	3.484	0.861	-0.028	-0.521
	DCIC2	3.308	0.965	-0.833	-0.06
	DCIC3	3.264	0.982	-0.776	-0.246
Employee Empowerment (EE)	DCEE1	3.473	0.922	-0.141	-0.427
	DCEE2	3.418	0.919	-0.325	-0.297
	DCEE3	3.846	0.783	1.372	-0.963
	DCEE4	3.421	0.891	0.006	-0.652
Circular Economy Practices (CEP)	CEP1	3.952	0.762	1.665	-0.92
	CEP2	3.908	0.772	1.15	-0.753
	CEP3	3.923	0.806	0.644	-0.745
Innovations in Green Process (IGP)	CEPIGP1	3.905	0.901	0.965	-0.93
	CEPIGP2	3.842	0.78	0.992	-0.739
	CEPIGP3	3.846	0.815	1.196	-0.891

Main Constructs/ Subconstructs	Code	Mean	Std. Deviation	Kurtosis	Skewness
Circular Dynamic Environment (CDE)	CEPCDE1	4.017	0.894	1.003	-0.92
	CEPCDE2	3.672	0.858	1.264	-0.89
	CEPCDE3	3.961	0.858	1.599	-0.96
Investment Recovery (IR)	CEPIR1	3.923	0.788	0.955	-0.722
	CEPIR2	3.934	0.814	0.402	-0.657
Sustainable Organisational Performance (SOP)	SOP1	3.795	0.697	0.909	-0.546
	SOP2	3.89	0.781	0.918	-0.685
	SOP3	3.952	0.762	1.665	-0.92
	SOP4	3.908	0.772	1.15	-0.753
	SOP5	3.923	0.806	0.644	-0.745
	SOP6	3.846	0.815	1.196	-0.891
	SOP7	3.853	0.808	0.634	-0.649
	SOP8	3.875	0.775	1.588	-0.874

6.2.6.2 Reliability Test

The data collection tool's reliability is considered highly important in a survey-based study. The researcher ensured the consistency and stability of the questionnaire in all circumstances by measuring reliability at key instances before and after data collection. Cronbach's alpha measures internal consistency to determine how closely connected a group of items is as a unit. A "higher" value of Cronbach alpha is frequently desired as evidence of connectedness among the items and respective constructs (along with coherent arguments and other statistical metrics). Inter-item assessments examine the scales or questions for internal consistency or reliability. Greater than 0.7 should be Cronbach's alpha coefficient value, as suggested by Malhotra and Grover (1998) and Flynn et al. (1990). Cronbach's alpha coefficient in this study was calculated to be 0.96, confirming the data's credibility and fitness for the intended purpose. It is a crucial component of the best survey research. Additionally, key respondent statistics are highlighted in the following section to improve understanding of the research problem.

6.3 Important Statistics about the Respondents' Demographic Profile

Demographic data about the respondents (experts from academics and company representatives) and the units they are representing help to better grasp background characteristics such as the hierarchical position of the respondent in the company and regarding the company, year of incorporation, ownership of the company, size of the company in terms of turnover, number of employees and market share. In this study, the researcher has included pertinent demographic questions to collect data in the survey. This valuable data helps the researcher to understand and interpret the data in the correct manner.

This section includes particulars of the respondent and the company being represented. The respondent and company's classification based on the collected demographic data is carried out and used for subsequent analysis. **Table 6.4** depicts demographic profiles.

6.3.1 Respondents Based on Organization's Annual Turnover

One of the widely accepted classifications of organizations is based on annual turnover. Ministry of MSME India guidelines provides a base (Ministry of Micro, 2018) by clearly identifying the categories as small, medium, and large companies. Thus, companies with annual turnover generating less than Rs. 5 crores are considered micro-level companies, and annual revenue generated between Rs. 5 crores to Rs. 75 crores are considered small-level companies. Annual turnover between Rs. 75 crores to Rs. 250 crores are considered medium-level companies, and an annual turnover of more than Rs. 250 crores to Rs. 500 crores and more are considered large-level companies. The respondents who participated in the survey belong to company categories like Micro, Small, and Medium-sized Enterprises (MSME) and Large-size companies. This study has considered six categories for a detailed understanding of the I4.0 propagation in the manufacturing sector. Thus, as depicted in **Figure 6.1** Very large scale is 45(16%), Large scale is 81(29%), Medium scale is 74(26%), Small-medium scale is 68(24%), Small scale 7(3%) and Micro level 5 (2%). Thus, according to the responses collected, large-scale industries 126 (45%) dominate the sample profile. Other categories contribute 154 (55%), which include medium, small and micro companies.

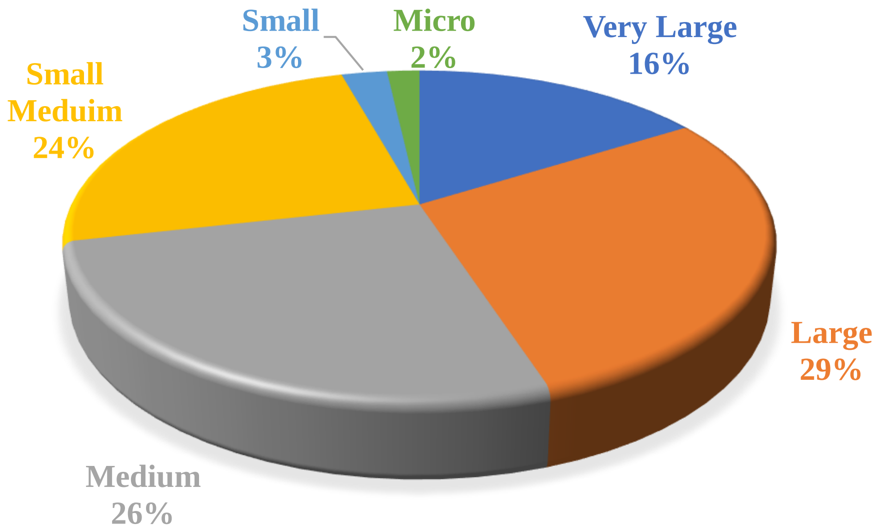

Figure 6.1: Respondents Based on Organization Annual Turnover

6.3.2 Respondents' Distribution based on Designation held in the Organizational Hierarchy

The I4A is leading to a number of developments in Indian manufacturing companies. This is primarily evident from the level of digitalization in industries and customers increased cyber literacy rate. Even though it seems to have entered the majority of organizations, the fact is it is just beginning. Many more are now gradually putting I4.0 into practice, but only after cautiously examining the viability, potential challenges, and perceived outcomes (G. Yadav et al., 2020). In accordance with this, our survey reveals that the sample respondents from all designation categories they occupy in the organizational hierarchy listed below are aware of the I4.0 vision and demonstrate a desire to embrace it. The respondents shown in **Figure 6.2** include members of top-level management such as the proprietor, chief operating officer, chief executive officer, chief financial officer, managing director, chief technical officer, 48 (17%), general manager/director/head of the business unit, 35 (13%), middle-level management such as the head of the department, 46 (16%), senior manager, manager, 46 (16%), senior and junior engineers, 85 (30%), and from lower-level respondents. Most of the sample falls within the Engineers 85 (30%) category, suggesting that these people are most familiar with the practical use and ramifications of the I4.0 efforts. Engineers in most organizations play a key role in connecting the higher-level managers and floor managers or people executing the plans, which is essential for I4.0

development. Furthermore, engineers are more into providing data, information, and knowledge to different functionalities about what is going on in the business.

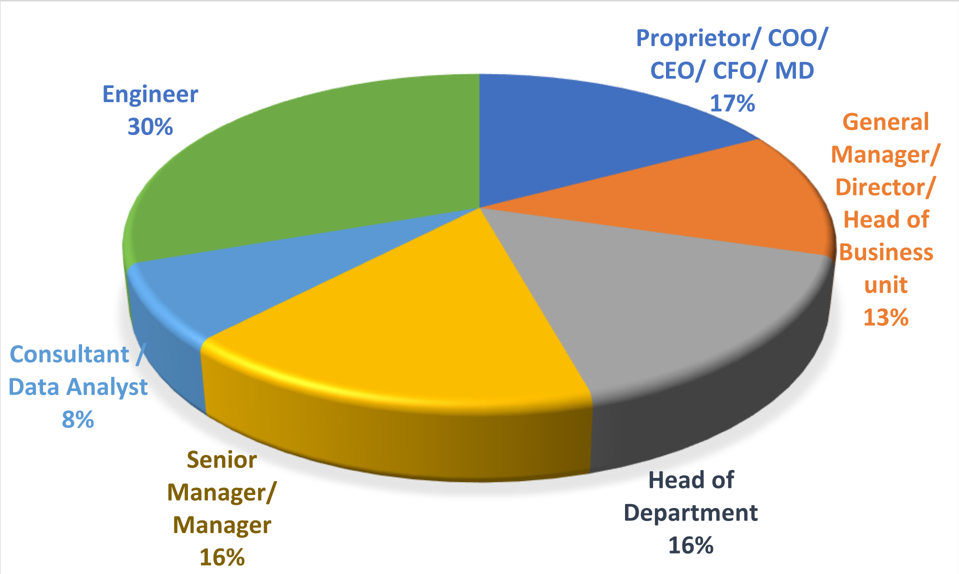

Figure 6.2: Representation of Respondents based on Designation held in the Organization

6.3.3 Educational Credentials of the Respondents

The educational credentials reflect the subject expertise and domain knowledge of the respondents. The distribution of respondents on the basis of their educational credentials are Ph.D., Doctorate in Business Management (DBM) 20 (7%), Masters, Postgraduate Diploma 155 (55%), Graduate 97 (35%), and Diploma 8 (3%). It is evident from the data, as shown in **Figure 6.3,** Master's degree holders are dominant in the sample, which confirms the presence of highly qualified respondents who possess a sound understanding of the study domain, ensuring the study's credibility. One interesting and value-added observation is the sizable contribution of 7% from Ph.D. and DBM degree holders. Ph.D. (research degree) and DBM degree-holding employees have been seen encouraging applied research projects within the organization owing to their extensive research skills, abilities, and comprehension of cutting-edge technologies. This momentum could be used to keep up with the rapid internal and external evolution as well as delineate, measure, and resolve potential issues cropping up as a result of I4.0 development (Shmatko et al., 2020). The inclusion of respondents with doctorates and postgraduate degrees also reflects companies' interest in innovation. The knowledge, experience, and abilities in resolving potential issues related to the deployment of I4.0 of the PGs and PhDs have certainly improved the validity of this study.

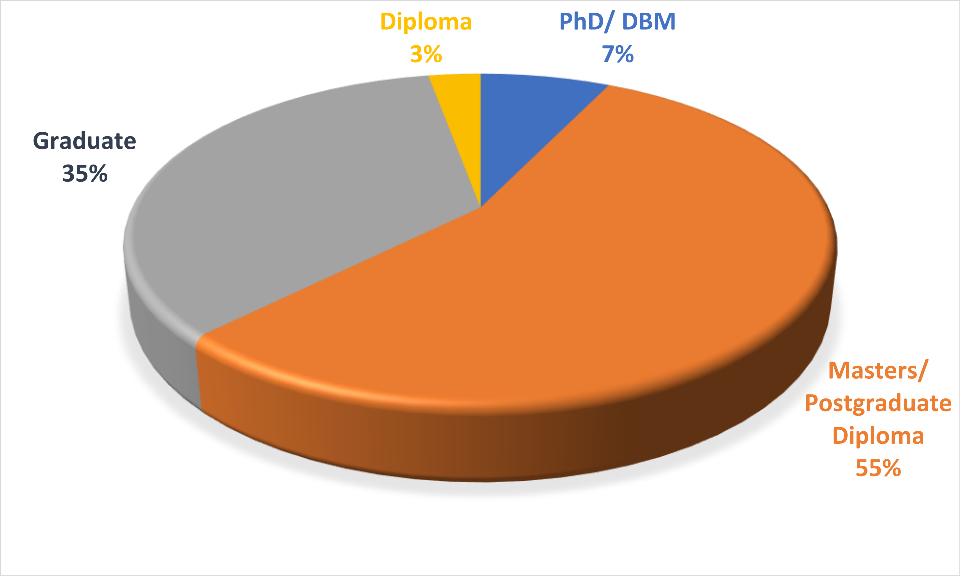

Figure 6.3: Representation of Respondents based on Educational Credentials

6.3.4 Service Experience of the Respondents in years

The respondent's work experience is one of the crucial components in any empirical study. It is observed from **Figure 6.4** that the respondent's distribution based on work experience is very close to the normal distribution. Respondents have service experience of more than 40 years 9 (3%), 31 to 40 years 16 (6%), 21 to 30 years 129 (46%), 11 to 20 years 100 (36%), and less than ten years 26 (9%). The dominant category is respondents belonging to the experience span of 21 to 11 years of experience 229 (82%). This states the current study has successfully captured the data from a diverse experience group of respondents.

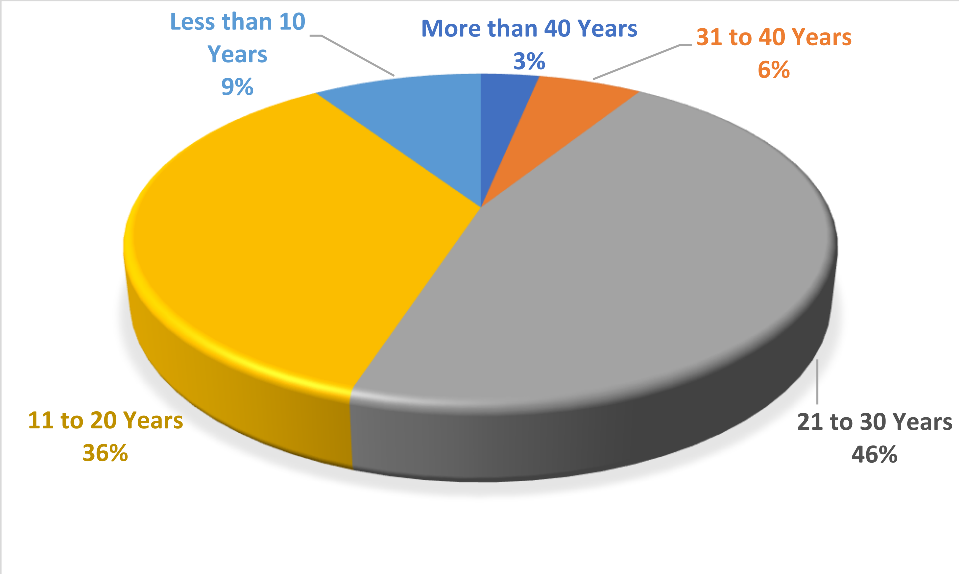

Figure 6.4: Representation of Respondents based on Service Experience

6.3.5 Respondents Based on the Manufacturing Sector Categorization

The researcher ensured the representation of diverse manufacturing sectors by reaching out to companies in different sectors. Every effort is made to build the sample as a true representative of Indian Manufacturing companies. These companies are differentiated based on the product width and length as well as the core capacity and capability, awareness, and application of digitalization, DC, and CEP in operations. The respondent companies are categorized based on the industry sector as reflected in **Figure 6.5,** showing the majority from Automotive 73 (26%), Metals and Machinery 46 (16%), Electrical and Electronics 37 (13%), Energy sectors 36 (13%), IT sector 18 (6%). The rest comprises sectors from Furniture Manufacturing, Textile, Food and Beverage, Defense/Aerospace equipment manufacturing sector, Engineering Services, Pharma Companies, Chemical Industry, Rubber/plastic manufacturing, Paper and Packaging manufacturing, and other manufacturing and production, all 70 (26%). The key finding of this survey is the high I4.0 acceptance rate in the Indian automobile industry. Statistics show this industry largely has understood the importance of DC implementation, CEP deployment, and SOP, corroborating past research results that this sector has highly embraced the prospects of I4.0 (Mckinsey, 2021).

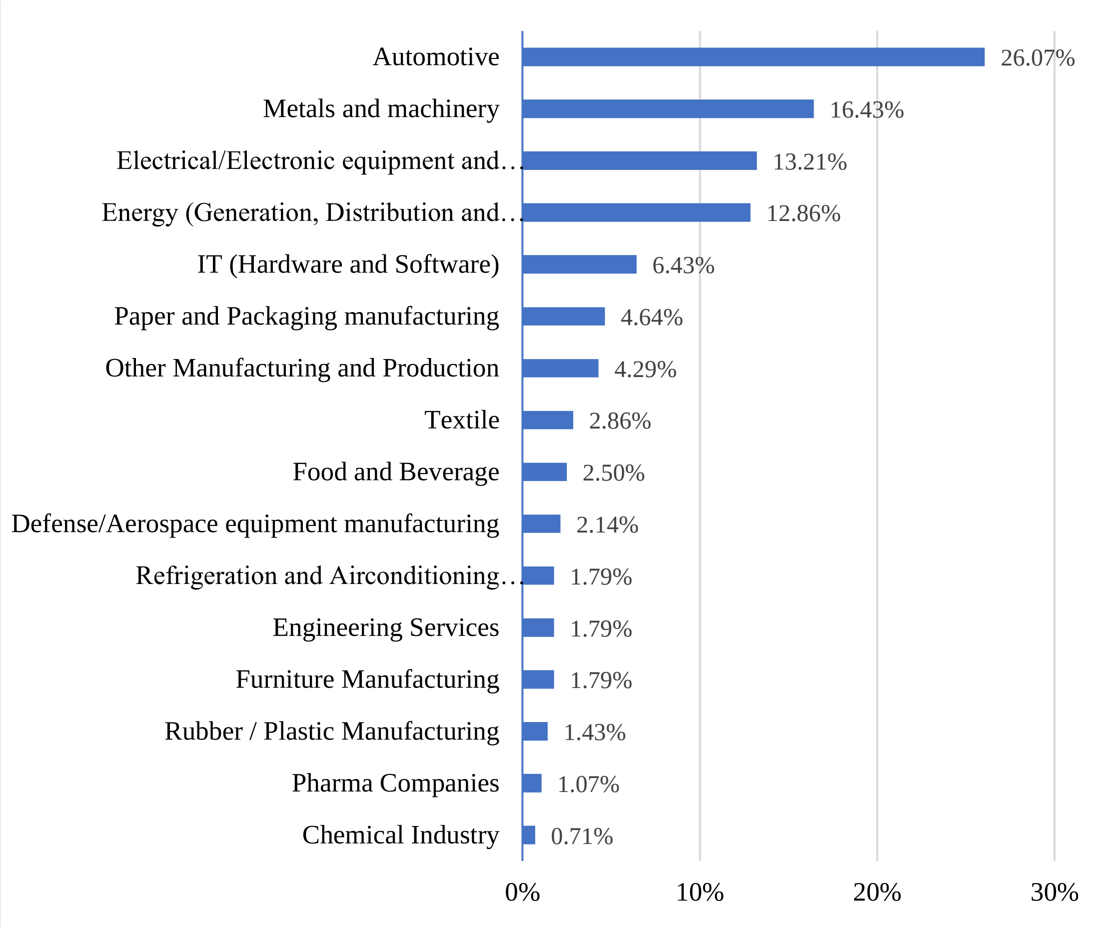

Figure 6.5: Representation of Respondents based on Manufacturing Sector Categorization

6.3.6 Respondents Based on Company Possession (Ownership)

The ownership of the company plays a significant role in critical and strategic decision-making. The more complex and iterative the decision-making process, the less agility and resilience. Hence, sample distribution based on company ownership needs prominent attention. This sample has collected data in three ownership categories. These categories, namely Multinational corporations 55 (20%), Private sector 202 (72%), and public sector 23 (8%), are depicted in **Figure 6.6.** The outcome signifies that the major portion contributes to the private sector, reflecting that these sectors are taking the I4.0 paradigm shift as an opportunity to achieve competitive advantage. Opportunities in the global business environment motivate these organizations to do better.

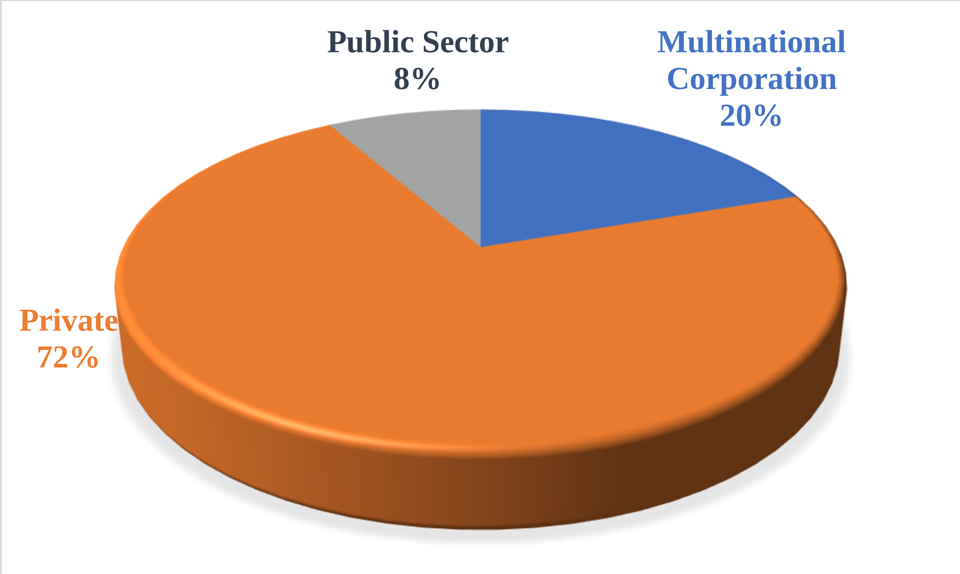

Figure 6.6: Representation of Respondents based on Company Possession

6.3.7 Respondents Based on the Number of Employees

The strength of employees is one of the key indicators of an organization's capacity and capability. The employee is an intellectual asset who brings innovation to processes and creates new strategies to bring sustainability. As depicted in **Figure 6.7,** the distribution of companies having employees more than 1000, i.e., 44 (16%), between 801 and 1000, i.e., 70 (25%), between 601 and 800, i.e., 86 (31%), between 401 and 600, i.e., 49 (18%), between 201 and 400, i.e., 14 (5%), between 51 and 200, i.e., 10 (4%), and less than 50, i.e., 7 (2%), show a normal pattern.

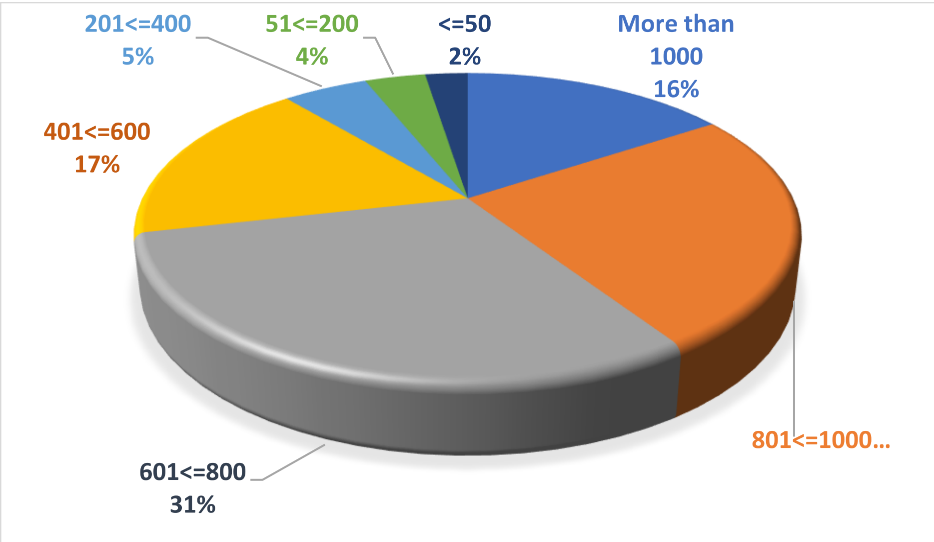

Figure 6.7: Representation of Respondents based on the Number of Employees in the Organization

Similarly, the employee number demonstrates that the sample is reasonably split across large, medium, and small organizations. Companies with employees in the range of 601 to 800 dominate the sample.

6.3.8 Respondents' Distribution Based on the Yearly Revenue Generated by the Organization

Yearly revenue generated by the organization shows its financial worth, which is an important consideration while investing in digital transformation and progressing towards a new paradigm shift. As shown in **Figure 6.8,** the represented companies' categories based on the company's annual revenue generation are distributed as more than 500 crores 45(16%), between 250 to 500 crores 81 (29%), between 75 to 250 crores 74 (26%), between 11 to 75 crores 68 (24%), between 5 to 10 crores 7 (3%), and less than 5 crore 5(2%). The companies belonging to the category between 250 to 500 crores and 75 to 250 crores, contributing 55%, dominate the sample. Organizations belonging to medium-scale categories also are not far.

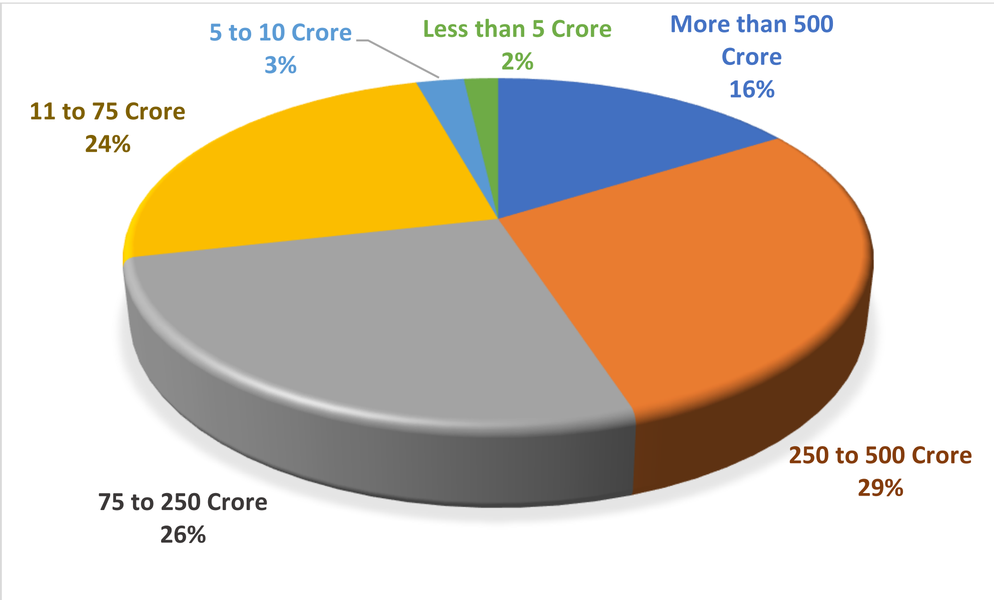

Figure 6.8: Representation of Respondents based on the Yearly Revenue Generated by the Organization

Table 6.4 demonstrates the specifics of the sample's demographic profile used in the study.

Table 6.4: Demographic Profile of Sample Undertaken for the Study

Specifics	Number of Survey Participants	The Proportion From the Total Sample
Corporate Designation		
Proprietor/COO/CEO/CFO/MD	48	0.17
General Manager/ Director/ Head of Business unit	35	0.13
Head of Department	45	0.16
Senior Manager/ Manager	46	0.16
Consultant / Data Analyst	21	0.08
Engineer	85	0.30
Educational Credentials		
PhD/ DBM	20	0.07
Masters/ Postgraduate Diploma	155	0.55
Graduate	97	0.35
Diploma	8	0.03
Service Experience in Years		
More than 40	9	0.03
31 to 40	16	0.06
21 to 30	129	0.46
11 to 20	100	0.36
Less than 10	26	0.09
Manufacturing Sector Categorization		
Automotive	73	0.26
Metals and machinery	46	0.16
Electrical/Electronic equipment and appliances	37	0.13
Energy (Generation, Distribution and Marketing) Services	36	0.13
IT (Hardware and Software)	18	0.06
Furniture Manufacturing	5	0.02
Textile	8	0.03

Specifics	**Number of Survey Participants**	**The Proportion From the Total Sample**
Food and Beverage	7	0.03
Defense/Aerospace equipment manufacturing	6	0.02
Engineering Services	5	0.02
Pharma Companies	3	0.01
Chemical Industry	2	0.01
Rubber / Plastic Manufacturing	4	0.01
Refrigeration and Airconditioning Manufacturing	5	0.02
Paper and Packaging manufacturing	13	0.05
Other Manufacturing and Production	12	0.04
Industry Possession		
Multinational Corporation	55	0.20
Private	202	0.72
Public Sector	23	0.08
Count of Employees		
More than 1000	44	0.16
801<=1000	70	0.25
601<=800	86	0.31
401<=600	49	0.18
201<=400	14	0.05
51<=200	10	0.04
<=50	7	0.02
Yearly Revenue in Indian Rupees		
More than 500 Crore	45	0.16
250 to 500 Crore	81	0.29
75 to 250 Crore	74	0.26
11 to 75 Crore	68	0.24
5 to 10 Crore	7	0.03
Less than 5 Crore	5	0.02

6.4 Analysis of the PLS-SEM Path Model's Outcomes

This research work intended to elucidate, examine and evaluate the critical role of the relationship of key drivers of I4A and I4A, key drivers of DC and DC, key drivers of CEP and CEP, and the collective impact of I4A, DC, and CEP on SOP, aiming to boost the competitive advantage of Indian manufacturing organizations. This is a unique and significant contribution to the study. The researcher has tried to uncover the hidden facets of I4A and present them systematically, which will help speed up I4.0's progression in manufacturing sector companies. The findings are also validated by comparing them with past studies and ground realities. The first-order and second-order constructs are identified through detailed SLR by focusing on extracting the most prominent extant studies contributing to the I4A domain. Furthermore, these constructs were discussed and deliberated with experts in the I4.0 realm before being accepted for study. **Appendix 1** demonstrates the constructs and the corresponding measuring indicators used in the current study. The data is collected from the manufacturing industries across India using a cross-sectional online survey. After the preliminary cleaning, the reliability test and other tests mentioned earlier in this chapter are carried out on the data set. For the proposed hypothesis mentioned earlier in **Chapter 3,** testing was carried out using the most appropriate and fitting PLS-SEM methodology utilizing the software package SmartPLS 3.0.
Further, the researcher has elaborated on the developed model evaluation in the following section.

6.4.1 Evaluation of the Model

Confirmatory factor analysis is chosen first to analyze collected survey data using the software Smart PLS 3.0. The measuring indicators showing a loading factor of less than 0.5 were dropped from the list. Thus, the final considered constructs and respective measuring indicators are elaborated in **Appendix 1.** The data analysis was conducted in two steps, as shown in **Figure 6.9.** first by evaluating the measurement model and further structural model using PLS-SEM to ensure the developed model's validity (Hair et al., 2012). This study has used reflective measures to measure the constructs. The reflective measurement model's reliability and validity are verified, and then the variable significance level and consistency are evaluated and confirmed using cross-validation of the model. This examination and confirmation of the measuring model demonstrated that all presumptive measures accurately reflect the relevant constructs (Choudhury and Harrigan, 2014).

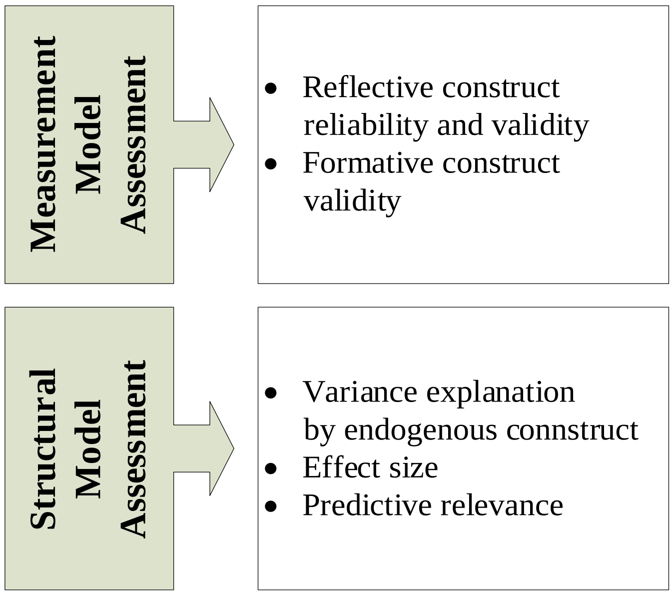

Figure 6.9: The Two-Stage Process of PLS Model Assessment.

6.4.1.1 Measurement Model Assessment

Since the measurement model focuses on how constructs and measured indicators relate to one another and primarily reflect the model's exterior layer, this model is also known as the outer model. Thus referring to **Table 6.5** and **Figure 6.10** it is noted that Circular Dynamic Environment (CDE), Circular Economy Practices (CEP), Capital Investments (CI), Dynamic Capabilities (DC), Industry 4.0 Adoption (I4A), Industry 4.0 Standards (I4S), Innovation Capabilities (IC), Innovation in Green Processes (IGP), Investment Recovery (IR), Organizational Strategies (OS), Risks Mitigation (RM), Supply Chain Agility (SCA), Stakeholders as Employees and Customers (SEC), Smart Products and Operations (SPO), and Sustainable Organizational Performance (SOP) reflects the factor loading above 0.7. Nevertheless, Digital Leadership (DL): (DCDL3=0.538), Industry 4.0 Technologies (I4T): (I4AI4T4=0.653), and Employee Empowerment (EE): (DCEE2=0.691) show the factor loading below 0.7 but not less than 0.50 (Kline, 2015) also the average factor loading of every construct is observed to be more than 0.70. Adding to this, removing the measuring indicators showing factor loading less than 0.7 does not significantly affect the reliability and validity of considered constructs, noting that the researcher has decided not to skip these indicators (Hair et al., 2014).

6.4.1.1.1 Internal Consistency Reliability and Convergent Validity

Composite reliability and Cronbach's alpha are frequently employed as indicators of internal consistency reliability. Although this reliability test assumes that all indicators are equally consistent and susceptible to the quantity of items mostly on a scale, Cronbach's alpha is the standard measure for determining internal consistency reliability (Hair et al., 2014). Additionally, Chin (1998) highlighted that composite reliability (CR) is perceived to be a more accurate predictor of reliability than Cronbach's alpha. Considering the deficiencies mentioned above, PLS-SEM uses an alternative internal consistency indicator termed CR. In an exploratory study, the permissible values for CR are between 0.6 to 0.7, but for greater accuracy, the values should be above 0.70 (Hair et al., 2011). Internal consistency reliability is absent if the CR values are less than 0.6.

Convergent validity "is the extent to which a measure correlates positively with alternative measures of the same construct" (Leguina, 2015). The average variance extracted (AVE) is used in this research as an indicator to confirm convergent validity. The values could range from 0 to 1, but for acceptable convergent validity, the AVE should be at least 0.5 (Hair et al., 2014). If the value is less than 0.5, more discrepancies are still present in the items. This indicates that the construct accounts for more than half of its indicator variation.

As shown in **Figure 6.10,** the construct is symbolized by a circle, and the rectangle symbolizes the measuring indicator. The arrows connecting the constructs and indicators represent the factor loading values marked above the arrow line. The internal consistency of the measuring indicators of the constructs is measured through their reliability. The measurement model's reliability is determined by the value of Cronbach's Alpha, and the CR of all the underlined constructs and AVE indicates convergent validity. In this study, the AVE values obtained for all constructs are more than the cut-off value of 0.5, suggesting that all constructs have acceptable convergent validity and reliability (Ringle et al., 2020).

6.4.1.1.2 Discriminant Validity

The construct validity is assessed using an indicator called discriminant validity. Moreover, it relates to the degree to which a collection of items distinctly estimates one construct out of a group of elements (Hair et al., 2013). Discriminant validity is the measure of checking the uniqueness of the constructs, which is determined by the Heterotrait Monotrait ratio (HTMT) criteria. The values obtained from the HTMT table, if greater than 0.9, are unacceptable, as it shows that the constructs chosen are not unique and the duplicity of the indicators present (Henseler et al., 2009). This study results from **Table 6.6,** which shows all constructs, the HTMT values obtained are below 0.9, representing that all constructs chosen are unique.

6.4.1.1.3 Multicollinearity Assessment

The measurement model is then examined for multicollinearity to understand the relationship between any two predictive constructs. In SEM model analysis, the multicollinearity is denoted by a variance inflation factor (VIF). Thus the VIF values obtained in this study are sufficiently below the threshold value 5, ranging from 1.1196 to 4.598, confirming that multicollinearity between predictor constructs considered is not a concern in this research (Kock and Verville, 2012).

Table 6.5: Results of the Reliability and Validity Test

Constructs	**Indicators**	**Loadings**	**Cronbach's**	**CR**	**AVE**
Circular Dynamic Environment (CDE)	CEPCDE1	0.919	0.8912	0.9322	0.8209
	CEPCDE2	0.9006			
	CEPCDE3	0.8983			
Circular Economy Practices (CEP)	CEP1	0.9176	0.8992	0.9371	0.8324
	CEP2	0.894			
	CEP3	0.9251			
Capital Investments (CI)	I4ACI1	0.9112	0.8588	0.9143	0.7809
	I4ACI2	0.9156			
	I4ACI3	0.8211			
Dynamic Capabilities (DC)	DC1	0.7924	0.8798	0.918	0.7374
	DC2	0.9081			

Constructs	Indicators	Loadings	Cronbach's	CR	AVE
	DC3	0.9082			
	DC4	0.8198			
Digital Leadership (DL)	DCDL1	0.7278	0.712	0.7464	0.5026
	DCDL2	0.8297			
	DCDL3	0.5382			
Employee Empowerment (EE)	DCEE1	0.7949	0.8318	0.889	0.669
	DCEE2	0.6913			
	DCEE3	0.8765			
	DCEE4	0.8933			
Industry 4.0 Adoption (I4A)	I4A1	0.7765	0.8084	0.8857	0.7219
	I4A2	0.9206			
	I4A3	0.8458			
Industry 4.0 Standards (I4S)	I4AI4S1	0.7895	0.734	0.7971	0.6629
	I4AI4S2	0.8381			
Industry 4.0 Technologies (I4T)	I4AI4T1	0.7864	0.751	0.8084	0.5144
	I4AI4T2	0.7115			
	I4AI4T3	0.712			
	I4AI4T4	0.6526			
Innovation Capabilities (IC)	DCIC1	0.7724	0.7492	0.8572	0.6672
	DCIC2	0.8096			
	DCIC3	0.8657			
Innovation in Green Processes (IGP)	CEPIGP1	0.8107	0.8156	0.8906	0.7312
	CEPIGP2	0.8452			
	CEPIGP3	0.9067			
Investment Recovery (IR)	CEPIR1	0.9024	0.7301	0.8807	0.7868
	CEPIR2	0.8714			
Organizational Strategies (OS)	I4AOS1	0.884	0.8453	0.9065	0.7636
	I4AOS2	0.8576			
	I4AOS3	0.8798			
Risks Mitigation (RM)	DCRM1	0.8293	0.8313	0.8973	0.7446
	DCRM2	0.8937			

Constructs	Indicators	Loadings	Cronbach's	CR	AVE
	DCRM3	0.8645			
Supply Chain Agility (SCA)	DCSCA1	0.9111	0.8912	0.9323	0.8212
	DCSCA2	0.909			
	DCSCA3	0.8984			
Stakeholders as Employees and Customers (SEC)	I4ASEC1	0.9221	0.9324	0.9517	0.8313
	I4ASEC2	0.93			
	I4ASEC3	0.9024			
	I4ASEC4	0.892			
Smart Products and Operations (SPO)	I4ASPO1	0.8169	0.9239	0.9384	0.6583
	I4ASPO2	0.88			
	I4ASPO3	0.8846			
Sustainable Organizational Performance (SOP).	SOP1	0.5863	0.8316	0.8958	0.7415
	SOP2	0.8329			
	SOP3	0.8943			
	SOP4	0.8425			
	SOP5	0.869			
	SOP6	0.7986			
	SOP7	0.8342			
	SOP8	0.7941			

Table 6.6: Results of Discriminant Validity (Heterotrait – Monotrait Ratios)

	CDE	CEP	CI	DC	DL	EE	I4A	I4S	I4T	IC	IGP	IR	OS	RM	SCA	SEC	SOP	SPO
CDE																		
CEP	0.576																	
CI	0.637	0.637																
DC	0.665	0.646	0.832															
DL	0.138	0.155	0.212	0.238														
EE	0.389	0.379	0.474	0.518	0.144													
I4A	0.555	0.863	0.710	0.693	0.223	0.459												
I4S	0.225	0.363	0.223	0.255	0.427	0.416	0.407											
I4T	0.226	0.280	0.285	0.245	0.133	0.306	0.456	0.234										
IC	0.386	0.414	0.537	0.573	0.247	0.589	0.521	0.445	0.422									
IGP	0.623	0.846	0.545	0.568	0.148	0.310	0.877	0.354	0.287	0.406								
IR	0.563	0.842	0.611	0.613	0.146	0.344	0.832	0.343	0.321	0.403	0.862							
OS	0.657	0.622	0.807	0.831	0.227	0.382	0.608	0.155	0.202	0.495	0.501	0.607						
RM	0.357	0.387	0.508	0.538	0.180	0.519	0.514	0.283	0.197	0.547	0.414	0.398	0.418					

	CDE	CEP	CI	DC	DL	EE	I4A	I4S	I4T	IC	IGP	IR	OS	RM	SCA	SEC	SOP	SPO
SCA	0.852	0.576	0.637	0.665	0.138	0.389	0.555	0.225	0.226	0.386	0.623	0.563	0.657	0.357				
SEC	0.825	0.556	0.587	0.616	0.159	0.334	0.526	0.209	0.188	0.339	0.576	0.542	0.609	0.332	0.832			
SOP	0.599	0.852	0.653	0.678	0.184	0.414	0.852	0.371	0.310	0.473	0.843	0.825	0.605	0.450	0.599	0.579		
SPO	0.359	0.350	0.480	0.519	0.185	0.510	0.476	0.237	0.171	0.526	0.373	0.355	0.406	0.803	0.359	0.330	0.413	

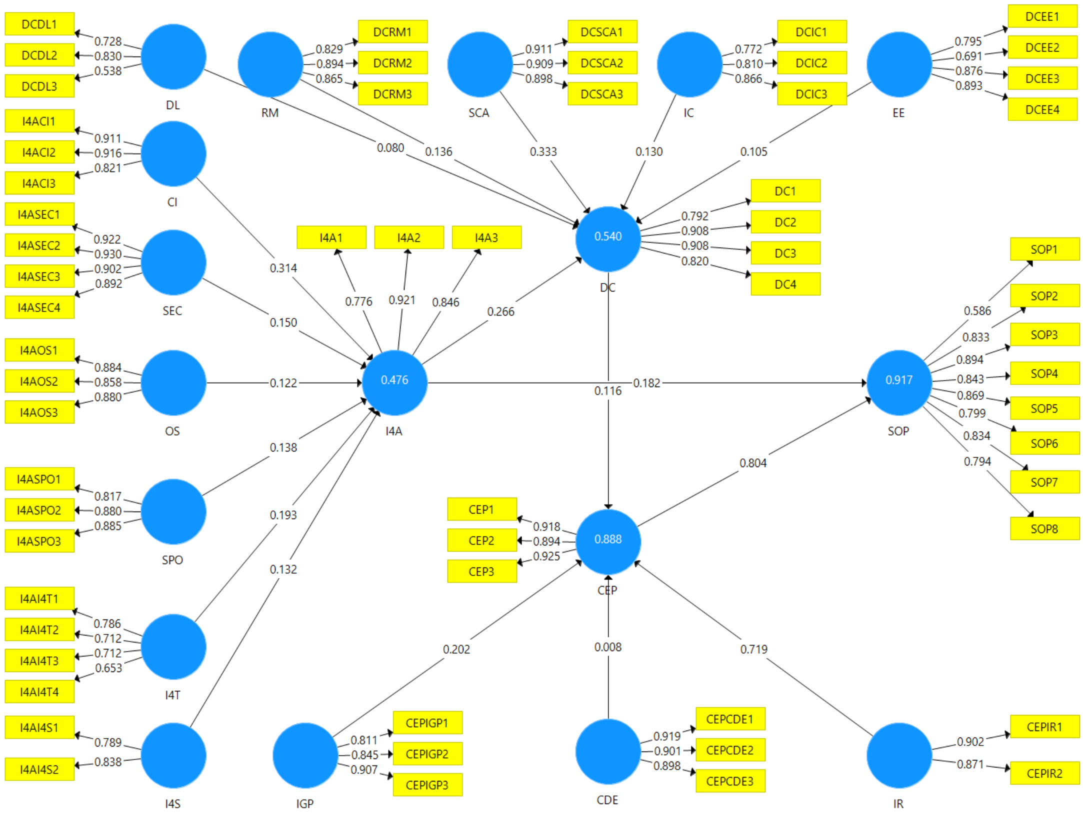

Figure 6.10: Measurement Model Representation

Note: Capital Investments (CI), Stakeholders as Employees and Customers (SEC), Organizational Strategies (OS), Smart Products and Operations (SPO), Industry 4.0 Technologies (I4T), Industry 4.0 Standards (I4S), Industry 4.0 Adoption (I4A), Digital Leadership (DL), Risks Mitigation (RM), Supply Chain Agility (SCA), Innovation Capabilities (IC), Employee Empowerment (EE), Dynamic Capabilities (DC), Innovation in Green Processes (IGP), Circular Dynamic Environment (CDE), Investment Recovery (IR), Circular Economy Practices (CEP), Sustainable Organizational Performance (SOP).

6.4.1.2 Structural Model Assessment

The structural model shows the relationship between the primary constructs, frequently referred to as an inner model. The nonparametric technique called bootstrapping is used to examine the statistical significance of several PLS-SEM outputs. This includes path coefficients, Cronbach's Alpha (construct validity and reliability), HTMT (discriminant validity), R^2 (coefficient of determination), SRMR (goodness of fit), Q^2 (predictive relevance ability), and F^2(effect size) values. Hence, to ensure that the results presented above are statistically significant, the bootstrapping procedure was performed using SmartPLS 3.0 software while taking into account the 5000 subsamples.

6.4.1.2.1 Assessment of the Variance in the Context as Explained by Endogenous Latent Constructs

The value of R^2 expresses the interpretative strength of the main constructs, and it varies from 0 to 1. A value close to 1 refers to high interpretative strength. Although, as per Hair et al. (2011), specifics provided for $R^2 \geq 0.75$ (significant), $0.75> R^2 \geq 0.50$ (moderate), and $0.50> R^2 \geq 0.25$ (low). The R^2 value of I4A: 0.476, DC:0.540, CEP:0.888, and SOP: 0.917, as depicted in the measurement model, shows that the endogenous construct SOP has conquered 91.7% variation resulting from exogenous constructs I4A, DC, and CEP collectively. This reflects that these three constructs strongly correlate with SOP and are worth considering for investigation. It assures that the developed model possesses significant predictive strength (Chin, 1998; Henseler et al., 2009) and proves its credibility in real-time industrial application and adoption.

6.4.1.2.2 Assessment of Effect Size

The effect size **(F^2)** quantified the contribution of endogenous constructs to the exogenous construct's R^2 value. As per Cohen et al. (1998), specifics provided for $\mathbf{F^2}$are ≥ 0.02 (small), $0.02> \mathbf{F^2} \geq 0.15$ (medium), and $0.15 > \mathbf{F^2} \geq 0.35$ (large). In this study, the value of effect size is I4A to DC:0.32 (large), DC to CEP: 0.46 (large), CEP to SOP: 2.6292 (large), and I4A to SOP: 0.17 (medium) indicates that the mediating constructs DC and CEP are more important contributors to SOP.

6.4.1.2.3 Assessment of Goodness of Fit

One more measure, like standardized root means square value (SRMR), represents how well the model is fit for real-life applications depicting the goodness of fit. The threshold value for SRMR is 0.08 (Sarstedt et al., 2017). For this model, the obtained SRMR values for the saturated model: 0.0672 and estimated model: 0.074, which is far below the cut-off value, confirm that this model has an excellent model fit and is suitable for practical application. It also ensures that there is no scope for error correlation and that all measuring indicators are coherent.

6.4.1.2.4 Assessment of Predictive Relevance

SmartPLS 3.0 applies the blindfolding procedure with Stone-Geisser's to calculate the Q^2 value (Akter et al., 2017; Henseler et al., 2016). Here the Q^2 is the measure of confirming the predictive relevance capacity of the constructs and ensuring the inner model's superiority. **Table 6.7** displays the cross-validated redundancy obtained for latent constructs indicating the Q^2 value in this research. The Q^2 values found in this study, as shown in **Table 6.7**, are higher than 0, which ascertains the predictive importance of the endogenous construct. Henseler et al. (2009) provide the specifics for Q^2 values are ≥ 0.35: high, $0.35 > Q^2 \geq 0.15$: medium and $0.15 > Q^2 \geq 0.02$: low. Referring to this from **Table 6.7,** we confirm that all the constructs have high predictive importance ensuring the relevance of all the selected constructs in this study.

Table 6.7: Results of Construct Crossvalidated Redundancy

	SSO	SSE	Q²
Circular Economy Practices	819.00	242.89	0.70
Dynamic Capabilities	1,092.00	685.18	0.37
Industry 4.0 Adoption	819.00	558.77	0.38
Sustainable Organizational Performance	2,184.00	956.89	0.56

6.4.2 Hypothesis Testing Investigation

The smart PLS simultaneously assesses the outer model, i.e., the measurement model, and the inner model, i.e., the structural model. The evaluation of the inner model evaluates the direct correlation among constructs considered for the study using path coefficients (β) and T-statistics. The path coefficients (β) and T-statistics were calculated in this investigation using the bootstrapping approach recommended by (Hair Jr et al., 2013) with a random sampling size of 5000. At a significance threshold of 0.05, T-statistics higher than 1.96 are deemed significant. The results from the structural model using the bootstrapping process are elaborated in **Table 6.8** which confirms that it is an excellent model as it meets all the criteria of the structural model. In the following part, the proposed hypothesis's viability is elaborated, which is mentioned in earlier **Chapter 3.**

Table 6.8: Findings obtained from Structural Model (Direct Effect)

SN	Hypothesis title	Hypothesis Coding	Structural Path	Standardized Path coefficient	T Statistics	P Values (*P<0.05, **P<0.01, *** P<0.001)	Decision (Accepted/ Rejected)
1	Capital Investments (CI) significantly positively impact Industry 4.0 Adoption (I4A).	H1a	CI -> I4A	0.314	4.8317	0.000***	Accepted
2	Stakeholders as Employees and Customers (SEC) involvement significantly positively impacts Industry 4.0 Adoption (I4A).	H1b	SEC -> I4A	0.1499	2.358	0.0185*	Accepted
3	Organizational Strategies (OS) significantly positively impact Industry 4.0 Adoption (I4A).	H1c	OS -> I4A	0.1218	1.9937	0.0464*	Accepted
4	Smart Products and Operations (SPO) significantly positively impact Industry 4.0 Adoption (I4A).	H1d	SPO -> I4A	0.1378	2.7653	0.0058**	Accepted
5	Industry 4.0 Technologies (I4T) significantly positively impact Industry 4.0 Adoption (I4A).	H1e	I4T -> I4A	0.1925	4.4663	0.000***	Accepted
6	Industry 4.0 Standards (IS) significantly positively	H1f	I4S -> I4A	0.1322	2.9346	0.0034**	Accepted

SN	Hypothesis title	Hypothesis Coding	Structural Path	Standardized Path coefficient	T Statistics	P Values (*P<0.05, **P<0.01, *** P<0.001)	Decision (Accepted/ Rejected)
	impact Industry 4.0 Adoption (I4A).						
7	Digital Leadership (DL) significantly positively impacts Dynamic Capabilities (DC).	H2a	DL -> DC	0.08	1.9868	0.0471*	Accepted
8	Risks Mitigation (RM) significantly positively impacts Dynamic Capabilities (DC).	H2b	RM -> DC	0.1362	3.2132	0.0013**	Accepted
9	Supply Chain Agility (SCA) significantly positively impacts Dynamic Capabilities (DC).	H2c	SCA -> DC	0.3325	7.4236	0.000***	Accepted
10	Innovation Capabilities (IC) significantly positively impact Dynamic Capabilities (DC).	H2d	IC -> DC	0.1296	2.4481	0.0145*	Accepted
11	Employee Empowerment (EE) significantly positively impacts Dynamic Capabilities (DC).	H2e	EE -> DC	0.1051	2.115	0.0346*	Accepted
12	Innovation in Green Processes (IGP) significantly positively impacts	H3a	IGP -> CEP	0.2023	5.5093	0.000***	Accepted

SN	Hypothesis title	Hypothesis Coding	Structural Path	Standardized Path coefficient	T Statistics	P Values (*P<0.05, **P<0.01, *** P<0.001)	Decision (Accepted/ Rejected)
	Circular Economy Practices (CEP).						
13	Circular Dynamic Environment (CDE) significantly positively impacts Circular Economy Practices (CEP).	H3b	CDE-> CEP	0.0078	0.2537	0.7997	Rejected
14	Investment Recovery (IR) significantly positively impacts Circular Economy Practices (CEP).	H3c	IR -> CEP	0.7195	16.529 3	0.000***	Accepted
15	Industry 4.0 Adoption (I4A) significantly positively impacts Dynamic Capabilities (DC)	H4	I4A -> DC	0.2658	5.3306	0.000***	Accepted
16	Dynamic Capabilities (DC) significantly positively impact Circular Economy Practices (CEP).	H5	DC -> CEP	0.1156	3.7328	0.0002** *	Accepted
17	Circular Economy Practices (CEP) significantly positively impact Sustainable Organizational Performance (SOP).	H6	CEP -> SOP	0.8036	30.028 9	0.000***	Accepted

SN	Hypothesis title	Hypothesis Coding	Structural Path	Standardized Path coefficient	T Statistics	P Values (*P<0.05, **P<0.01, *** P<0.001)	Decision (Accepted/ Rejected)
18	Industry 4.0 Adoption (I4A) significantly positively impacts Sustainable Organizational Performance (SOP).	H7	I4A -> SOP	0.1821	6.0625	0.000***	Accepted

Significant at *P<0.05, **P<0.01, *** P<0.001

6.4.2.1 Direct Effect Evaluation

This study has 19 hypotheses evaluated at a 95% confidence level considering T ≥ 1.96 and p ≤ 0.05 to examine the direct inter-construct effect. **Table 6.8** reflects the path coefficients (β), T statistics, and P values, representing Capital Investments (β= 0.314, T=4.8317, P= 0***), Stakeholders as Employees and Customers (β= 0.1499, T=2.358, P= 0.0185*), Organizational Strategies (β= 0.1218, T=1.9937, P= 0.0464*), Smart Products and Operations (β= 0.1378, T=2.7653, P= 0.0058**), Industry 4.0 Technologies (β= 0.1925, T=4.4663, P= 0***), I4.0 Standards (β= 0.1322, T=2.9346, P= 0.0034**) are significantly positively impacted I4A.

Digital Leadership (β= 0.08, T=1.9868, P= 0.0471*), Risks Mitigation (β= 0.1362, T=3.2132, P= 0.0013**), Supply Chain Agility (β= 0.3325, T=7.4236, P= 0***), Innovation Capabilities (β= 0.1296, T=2.4481, P= 0.0145*), Employee Empowerment (β= 0.1051, T=2.115, P= 0.0346*), are significantly positively impacts Dynamic Capabilities. Similarly, Innovation in Green Processes (β= 0.2023, T=5.5093, P= 0***), Investment Recovery (β= 0.7195, T=16.5293, P= 0***) are significantly positively impacts Circular Economy Practices. A circular Dynamic Environment (β= 0.0078, T=0.2537, P= 0.7997) does not significantly impact Circular Economy Practices.

I4.0 Adoption (β= 0.2658, T=5.3306, P= 0***) significantly positively impacts Dynamic Capabilities. Dynamic Capabilities (β= 0.1156, T=3.7328, P= 0.0002***) significantly positively impact Circular Economy Practices. Circular Economy Practices (β= 0.8036, T=30.0289, P= 0***) significantly positively impact Sustainable Organizational Performance and I4.0 Adoption (β= 0.1821, T=6.0625, P= 0***) significantly positively impacts Sustainable Organizational Performance.

Thus on the basis of the above-mentioned direct relationship hypotheses, H1a, H1b, H1c, H1d, H1e, H1f, H2a, H2b, H2c, H2d, H2e, H3a, H3c, H4, H5, H6, and H7 are accepted, and hypothesis H3b is rejected.

6.4.2.2 Mediation Analysis

The importance of I4A in this model's explanation of SOP variance is examined through bootstrapping in a mediation analysis (Hayes, 2017) to calculate the integration of DC and CEP mediation effects. Bootstrapping is an effective method for mediation in assessing small sample sizes since it does not presuppose the form of the sampling distribution. **Table 6.9** elaborates on the outcomes of the mediation analysis in the context of the relationship between I4A and SOP while taking into account the joint mediation role played by DC and CEP. The outcome shows that I4A -> SOP (β =0.1821, T=6.0625, P=0.000***) indicates statistical significance where a P value is below 0.001 and an indirect relationship where DC and CEP act as a mediator i.e., I4A -> DC -> CEP -> SOP (β =0.647, T=10.6273, P=0.0087***) indicates statistical significance where P-value is below 0.01. It is noted that both the direct and indirect impacts are significant where the impact intensity of the indirect effect is more than the direct effect, indicating that DC and CEP partially mediate the relationship between I4A and SOP.

Further, the kind of partial mediation is confirmed through the calculation, i.e., path coefficients (0.749*0.150 =0.12), reflecting that both the effects are positively significant with the derived score of 0.12. This indicates that DC and CEP provide complementary mediation (Zhao et al., 2010) in the relationship between I4A and SOP. Thus, hypothesis H8, i.e., Integration of Dynamic Capabilities (DC) and Circular Economy Practices (CEP), positively mediate the indirect association between Industry 4.0 (I4A) and Sustainable Organizational Performance (SOP), is accepted.

Thus, we confirm that for the I4A model to achieve SOP, this study offers empirical support for the mediating roles of DC and CEP. The results demonstrate that implementing I4.0 and integrating DC and CEP enhances SOP.

Table 6.9: Mediation Analysis Outcome

	Path Coefficient	T-value	P Value	Decision (Accepted/ Rejected)
Direct Relationship I4.0 Adoption -> SOP	0.1821	6.0625	0.000***	Accepted
Indirect Relationship Industry 4.0 Adoption ->Dynamic Capabilities ->Circular Economy Practices -> SOP	0.647	10.6273	0.0087***	Accepted

Note: Significant at *P<0.05, **P<0.01, *** P<0.001

6.5 Mathematical Model Development using Regression Analysis

A mathematical expression describing a realistic scenario is created through the technique of mathematical modeling in order to make a prediction or offer insight for a clear understanding of complex systems. Thus, regression analysis is a statistical method used to create a mathematical model for assessing the interdependence between variables that have cause-and-effect relationships. Establishing the linear relationship equation between dependent and independent variables and exploring the relationship between the dependent variable and one independent variable are the main objectives of univariate regression. Multilinear regression is the name given to regression models with one dependent variable and multiple independent variables. It is based on the assumptions of normality, linearity, lack of extreme values, and missing value analysis. Regression models are frequently used by empirical communication between researchers and researchers in other domains to investigate moderation hypotheses. It is frequently used to test the linear moderation hypothesis when the independent variable “x” and the moderator “m” are dichotomous or continuous. This is done by including the product of x and m in the model of the dependent variable y.

Sir Francis Galton was the first to put forth the idea of linear regression in 1894. A statistical test called linear regression describes and measures the relationship between the variables being investigated in a data set. Chi-square, Fisher’s exact, t-test, and analysis of variance (ANOVA) are examples of univariate statistical tests that do not permit accounting for the impact of additional factors or confounders during analyses (Chang, 2004). However, the tests that allow the researcher to control the impact of confounders in understanding the relationship between two variables are partial correlation and regression (Chang, 2003).

The researchers frequently seek to comprehend or associate two or more independent (predictor) factors in engineering and management research in order to forecast a result or dependent variable. This might be interpreted as how risk factors, predictor variables, or independent variables contribute to estimating the likelihood that a problem will arise. This possibility to comprehend the relationship between "risk variables and problem" is provided by both correlation and regression (Gaddis and Gaddis, 1990). Regression analysis uses mathematics to define this link, whereas correlation offers a quantitative technique of evaluating the degree or strength of a relationship between two variables. A dependent variable's value can be predicted using regression analysis if at least one independent variable is known.

The equation $y = mx + c$, which describes the line of best fit for the connection between the dependent variable (y) and the independent variable (x), is used in the linear regression analysis (independent variable). The regression coefficient, or r^2, denotes how variable y is due to x.

The following justifies the need to use a linear regression model:

a) The descriptive analysis aids in determining how strongly the outcome (the dependent variable) and predictor variables are correlated.
b) Adjustment analysis accounts for the influence of covariates or confounders.
c) Predictors help identify the critical risk factors that impact the dependent variable.
d) Prediction's range - These aid in determining how much a change in the independent variable by one "unit" will affect the dependent variable.
e) Prediction - It aids in calculating the number of new cases.

As explained earlier, Regression analysis is a fundamental tool in mathematical modelling. Its relevance in mathematical modelling is significant here:

- To understanding Relationships (strong or weak) between independent variables to a dependent variable (Independent Variable: I4A, DC, CEP and Dependent Variable SOP).
- To predict and forecast (estimate) future values of a dependent variable based on the values of independent variables.

- To estimate and quantify the impact on the dependent variable.
- To validate the findings of SMART PLS. Regression analysis has purposely chosen to validate relationship if statistically significant, helping to assess the model's validity and relevance.
- To identify which constructs are most relevant in explaining variations in the dependent variable. This aids in simplifying SMART PLS model and improving their interpretability.
- To help policymakers make informed decisions by quantifying the relationship between policy variables and outcomes.

In the current context, the researcher has extended the outcome of the developed operational framework for real-world applications using the multiple regression method. The SOP variable is dependent on the other three independent variables I4A, DC, and CEP.

Table 6.10, Table 6.11, Table 6.12, Table 6.3, Table 6.14, and **Equation 1** obtained from the software package SPSS v23 present profound agreement with the Smart PLS model. The multiple regression model established and endorsed that I4A and CEP have a major share compared to DC in advancing the SOP, as reflected in **Equation 1.** Organizations thereby should be more focused on building the capacity to push I4A and CEP, including promoting DC.

The framework comprehensively captures the relations of I4A, DC, CEP, and SOP by systematically analyzing the contributing components and then posing them to create a balanced movement toward achieving the goal. This mathematical model motivates all the decision makers and strategists to consider these three independent variables as key to long-term sustainability. This model also has the potential to assess the key processes structured into three vertical levels: technological, process and development, integrated through the CEP.

The period of digitalization has been attributed in large part to I4.0. To achieve the triple bottom line of sustainable business strategies, the DCs, and CEPs, have drawn attention to its implications for sustainable development in the context of I4A. This mathematical model's goal is to represent the wide aspects of sustainable growth and look at the major study fields that include the aforementioned viewpoints under the I4.0 framework. The main conclusions are that conceptual analysis; even though it is important, the mathematical model is considered more appropriate for implementation in the industrial world. In the framework of I4.0 and SOP, the role of DC and CEP is also gaining importance.

This mathematical model combines the most important and relevant development themes by quantifying everyone's contribution and its impact on the organization's overall sustainability, which has never been calculated and validated by any researcher/study before. Along with this, the study's outcome has also been discussed with the experts mentioned earlier to increase the research work's credibility. The findings were agreeable and appreciated by the experts, making this study one of its kind and unique. Also, as ensured by the experts and endorsed through the prior studies, the current study's findings can be generalized and applied to a real-world scenario.

SOP= 0.11 +I4A*0.213 +DC*0.075 +CEP*0.665 ------- (1)

Table 6.10: Regression Model Description

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	CEP, DC, I4A[b]	----	Enter

a. Dependent variable: SOP b. All requested variables entered

Table 6.11: Regression Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.947[a]	0.897	0.896	0.20358	0.897	780.918	3	269	0

a. Predictors: (Constant), CEP, DC, I4A

Table 6.12: ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	97.093	3	32.364	780.918	.000[b]
	Residual	11.148	269	0.041		
	Total	108.242	272			

a. Dependent Variable: SOP

b. Predictors: (Constant), CEP, DC, I4A

Table 6.13: Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.11	0.105		1.049	0.295
	I4A	0.213	0.039	0.185	5.473	0
	DC	0.075	0.028	0.067	2.713	0.007
	CEP	0.665	0.029	0.751	22.55	0

a. Dependent Variable: SOP

Table 6.14: Correlations

		I4A	DC	CEP	SOP
I4A	Pearson Correlation	1	.589**	.799**	.825**
	Sig. (2-tailed)		0	0	0
	N	273	273	273	273
DC	Pearson Correlation	.589**	1	.574**	.607**
	Sig. (2-tailed)	0		0	0
	N	273	273	273	273
CEP	Pearson Correlation	.799**	.574**	1	.937**
	Sig. (2-tailed)	0	0		0
	N	273	273	273	273
SOP	Pearson Correlation	.825**	.607**	.937**	1
	Sig. (2-tailed)	0	0	0	
	N	273	273	273	273

** Correlation is significant at the 0.01 level (2-tailed)

6.6 Conclusion

This chapter offered a comprehensive description of the survey data interpretation and analysis of results obtained in two phases. The first phase entails collecting survey data, preprocessing data, and preliminary data analysis using the SPSS v23 software package, which is required to undertake the PLS-SEM investigation. After ensuring that all essential parameters satisfied all assumptions, the second phase proceeded using PLS. The SmartPLS 3.0 SEM software package was used to analyze the two-stage path model in the second phase. The measurement model is evaluated in the first stage to determine convergent validity and internal consistency reliability. With reliable and valid data, the next process was to initiate the second stage, the structural model assessment, to test the hypotheses. Therefore, addressing this study's findings, one of the 19 hypotheses was rejected, while the rest were significantly confirmed. Finally, the following chapter will describe comprehensive research findings with appropriate justifications for both accepted and rejected hypotheses. Further, the model outcome its extended through the mathematical model to predict SOP, and expert involvement ensures the credibility of the developed model.

7 Discussions, Recommendations, and Conclusion

7.1 Introduction

The I4.0 paradigm has received increasing attention in the industrial sector due to notions of its advantages, including cost savings, superior quality, improved performance, increased productivity, and significant investment returns. It has completely transformed the manufacturing sector as it replaces traditional systems and processes. Various countries have debuted several national initiatives in recent years, especially developing ones like India, to execute company digitalization projects in their manufacturing, service, and other vital sectors. As the manufacturing industry accounts for a larger share of the country's GDP, these initiatives have been rapidly advancing in that sector with the idea of harnessing its maximum potential to obtain SOP to get a competitive advantage. Companies worldwide are pursuing excellence in order to meet SOP since it is a fundamental expectation from all stakeholders (i.e., customers, suppliers, ecological, social, and environmental concerns priority requirement of the product, services from customers, employees, business partners, competitors, etc.) Indian manufacturing organizations are actively pursuing the I4A. Companies are convinced of the prospects ascertained by I4.0, and the momentum is constantly and progressively increasing (Castelo-Branco et al., 2019). The huge potential benefits and opportunities of I4.0, which might have global repercussions for business models, motivate manufacturing companies to embrace it.

Even if this appears to be the case, Indian manufacturing organizations have not moved as quickly as those in developed nations while having admirable and inspiring aspirations. The lack of a clear structure and the scarce resources available to inspire company trust in the consequences of I4.0 may be the main causes of the slow speed (Sharma et al., 2021). The present shift in the digital technology paradigm is evidence that manufacturing companies actively look for ways to seize I4.0's potential. However, the existing literature on implementing I4.0 capabilities does not contain enough empirical foundation to support the research in this field. Although implementing I4.0 seems promising, many businesses still have difficulty doing so since there is no clear framework for identifying and assessing the key I4.0 KSFs and KPIs and I4.0 risks mitigation framework. As a result, the enterprises are prevented from realizing the potential of I4.0, which could have made their business model progressive, competitive, and sustainable.

The evidence from the research literature suggests that emerging nations face more significant challenges than their counterparts in developed countries when it comes to implementing cutting-edge technologies, managing dynamic resources, and implementing capabilities compliant with I4.0. They also face tremendous pressure to implement CEPs (Khan et al., 2020b). There has been limited industrialization, scant technology adoption, very few reconfigurations of resource capabilities, and little widespread adoption of CEPs in emerging economies due to their focus on product harvesting and commercialization. As a result, they frequently continue to lag behind developed economies (Bag et al., 2021a; Khan and Turowski, 2016b).

The level of investment in I4.0-related technologies is always influenced by other factors, such as differences in culture, inadequate digital skills and academic credentials, a scarcity of digital infrastructure, economic volatility, and a huge working population. As per technology, there are multiple types and intensities of barriers to implementing the I4.0 vision in developing countries than in developed countries for integrating I4.0 practices in the manufacturing organization's business model. The idea of I4.0 is presently in its inception and developing gradually in the industrial industry (Sharma et al., 2021). The influence of emerging technologies and their real effects on the industrial performance of companies are limitedly understood and highly unclear in emerging countries. I4A presents significant complexity due to the lack of clarity required to systematically examine and evaluate its predicted risks and expected SOP outcomes. This study is an effort to address this problem in response. Creating a sustainable integrated model to quantify and assess important I4.0 KPIs and I4.0 risks aims to make it easier for businesses and policymakers to move toward the I4.0 paradigm (Raut et al., 2021). Furthermore, responding to the earlier research literature by investigating the interaction between I4A and SOP could benefit from the integration of DC and CEP.

7.2 Recapitulation of the Study's Findings

The thesis commenced by outlining the research questions, objectives, and scope of the study while highlighting the most recent developments in the selected research area and reiterating the necessity of carrying out the current investigation. The study uses quantitative and qualitative LR techniques to address the research questions and framed objectives. The outcomes of both LR methodologies aid in creating the research plan. The initial step in addressing and designing the SOP evaluation framework is to examine the two exploratory case studies to become familiar with the current status of I4.0 implementation, perception, and I4A readiness. Using the most popular MCDM method, EDAS, the first exploratory case study prioritized the I4.0 KSFs based on the identified KSFs. This study's important finding is that the internet network infrastructure and current technological capability to deploy I4.0 are the most important KSF.

The second exploratory study evaluates the interrelationship among the identified I4.0 KPIs and prioritizes the I4.0 risks according to these considered KPIs using the most preferred MCDM methods adopting an integrated approach using DEMATEL, CRITIC- MABAC, PROMEETHEE II, MOORA, and COPRAS methods. The outcome of this study indicates that cost is the most significant effect KPI and that information security is the most important cause KPI. This also demonstrates the technological and social risks impacting most of the I4.0 paradigm shift.

Additionally, the outcomes of the LR and exploratory case studies led to a response to the study problem of investigating the link between the drivers of I4A, DC, and CEP and I4A, DC, and SOP, extending this to investigate the relationship among I4A, DC, CEP and their combined impact on the SOP evaluation. The PLS-SEM method is used for derived hypothesis testing by deploying the SmartPLS 3.0 SEM software package. The hypotheses H1a, H1b, H1c, H1d, H1e, H1f, H2a, H2b, H2c, H2d, H2e, H3a, H3c, H4, H5, H6, and H7 are accepted, and hypothesis H3b is rejected. Also, the integration of DC and CEP, known as hypothesis H8, is acknowledged as a beneficial mediating factor in the indirect relationship between I4A and SOP refer to **Chapter 6.** The discussions on the study findings are elaborated on in the next section.

7.3 Discussions on Study Findings

According to the results of exploratory case study 1, referring to **Chapter 4,** reliable internet infrastructure, low latency, and seamless connectivity are all essential for the I4A to improve its effectiveness. Consequently, this study aims to boost confidence and guide manufacturing organizations in the right direction for successfully implementing the I4.0 paradigm; the KSFs have been prioritized based on the KPIs. This study uses professional ideas from the industrial sector to make it realistic and doable in practice. According to the results of exploratory case study 2, referring to **Chapter 5** is that, one of the most important KPIs for mitigating risk-related concerns and successfully implementing I4.0 practices is information security. This is achieved using standard protocols and guidelines for data collection, processing, CC and data analytics, sensors, and IoT devices. A necessary facility in I4A is the cost-efficient, adaptable, high-performance infrastructural facility that offers uninterrupted internet access to serve key decision-makers in real-time. This confirms the claims made by Terra et al. (2021) and Morgan et al. (2021), emphasizing the calls for emerging technology infrastructure, a service-based business strategy integrated with information security, and a customer-centric approach is required to deal with unpredictable profitability, to derive cost-effective solutions.

Therefore, a robust technological infrastructure is required to handle challenges with cyberattacks, data integrity, and interconnectivity among interlinked devices like machinery, sensors, and storage systems. Additionally, the instantaneous decision-making abilities through digitalization across all of the value chain minimize the technological risks (Kamble et al., 2018a). Hence to enable a business model compatible with I4.0, the current technological infrastructure needs to be adjusted, modified, and modernized.

The management of human resources and a people-centric strategy continue to be important considerations. Organizations need to have reasonable and forward-thinking human resource policies that emphasize employees' work-life synergy, personal growth, and a respectful, empowering, and productive atmosphere that will motivate them to offer their best. As a result, it's crucial to look after the individuals responsible for creating and putting into practice technological solutions to foster a sense of ownership and belonging within the workforce can further reduce social risks.

The details of discussions on the findings of the final research problem are delineated as explained below. This study's primary goal is to examine how the four essential constructs of I4A, DC, CEP, and SOP, relate to one another. The objective is to provide the mechanism and guidelines to the decision-makers for achieving SOP by considering the synergistic effect of integrating DC and CEP while implementing I4.0 practices to approach SOP. In this study, the researcher has tried to explore the direct relationship between I4A and SOP and its indirect connection to SOP while considering the mediating effect of DC and CEP. Simultaneously study has examined the broader ambit of key drivers of I4A, DC, and CEP and their respective impact on getting a wider perspective and understanding their contribution to achieving SOP. This study's theoretical framework is based on the DCV and contingency theories, where the DCV theory examines the importance of key drivers for I4A, DC, and CEP and their individual effects on these constructs. The contingency theory examines the relationships between primary constructs I4A, DC, CEP, and SOP. The results shown by models' quality estimation parameters depict in **Chapter 6** that the developed model has excellent goodness of fit, a large effect size, and high predictive and relevance power. This confirms the credibility and integrity of the model. This also assures the robustness of the model and relevance for real-life manufacturing industry applications to derive engineering and management-related implementation policies for advancing toward I4A. A 5 percent significance threshold level was used to examine a total of derived nineteen hypotheses, out of which one hypothesis was rejected, and the results accepted eighteen hypotheses. The significance of hypothesis testing results is addressed in this section ahead. Furthermore, researcher elaborates on the comprehensive deliberations and provide legitimate recommendations based on the study findings.

7.3.1 Capital Investment Relationship with Industry 4.0 Adoption

The effective deployment of the key drivers for I4A is vital for enhancing its capabilities and fostering the manufacturing industry's competitive edge aiding in promoting the progression of I4A. Many researchers address capital investment as one of the important drivers for I4A (Kiel et al., 2017). The organization's ability to conduct a cost-benefit analysis prior to investing is critical when choosing I4.0 plans and investment assets. In order to continue to be successful in the intense external market contention, companies believe that there is a need to become sensitive and responsive to the dynamic changeovers happening globally. Nevertheless, the post-Covid-19 pandemic has made it a once-in-a-lifetime privilege to select advanced technologies. Developing research and development facilities to train human resources are a few investment opportunities to adopt the evolving business model and thrive in line with the demands of the present time (Adámek and Meixnerová, 2020; Fayomi et al., 2020). Businesses are looking for significant and rapid returns on investments with the mindset of no longer waiting and being ready to take on challenges through adopting smart investment strategies. Thus, the acceptance of hypothesis (H1a) that Capital Investments (CI) significantly positively impacts I4.0 Adoption (I4A) has tried to provide new insights into the decision-making for the necessity of CI in I4.0 compliant infrastructure development, supporting the recommendations of the studies (Gadekar et al., 2022; Lepore et al., 2021).

7.3.2 Stakeholders as Employees and Customers' Relationship with Industry 4.0 Adoption

Stakeholders as employees and customers is a crucial driver of I4A. An intelligent and proficient employee can adapt the technological changes efficiently and effectively. Although companies are adopting automation on a large scale, skilled employees remain in their place to handle and maintain the automation-imbibed infrastructure. This study findings show that hypothesis (H1b) Stakeholders as Employees and Customers (SEC) involvement significantly positively impact Industry 4.0 Adoption (I4A) is accepted. This depicts that the companies should investigate their possibilities for ongoing training and development of the present employees, which will comprise a dedicated team of software management professionals, data scientists, technicians, and management leaders prepared to work independently. This study suggests that concentrating on building an internal training and development center can boost employee capabilities to deal with customer requirements successfully. Businesses that manage customers require no more effort beyond taking excellent care of their employees to achieve good customer relationship management; thus, employees and customers can complement each other while reaching the capabilities goals of I4A. Customer-focused initiatives and programs provide a comprehensive approach to enhancing I4.0 capabilities and can leverage the competitive advantage. Thus this study is an effort to extend ideas of the outcomes of the studies (Müller and Voigt, 2018; Neumann et al., 2021).

7.3.3 Organizational Strategies Relationship with Industry 4.0 Adoption

One of the key drivers for harnessing I4A is precisely identified and structured organizational strategies. Higher productivity and talent acquisition performance can be attributed to the leadership roles, a supportive environment, and accurately anticipated responsive action plans to deal with sources of uncertainty. This study has accepted the hypothesis (H1c) that Organizational Strategies (OS) significantly positively impact Industry 4.0 Adoption (I4A). Thus, we recommend the implementation of innovative operational initiatives that include a strong vision, teamwork to constantly improve the workforce skills capabilities, established administrative policies for technology adoption, and management techniques to capitalize on more incredible progression to achieve I4A. Consequently, this work has significantly expanded previous research findings (Luthra and Mangla, 2018; Mittal et al., 2018b; Schumacher et al., 2019).

7.3.4 Smart Products and Smart Operations Relationship with Industry 4.0 Adoption

The extent of personalization offered by the company and its potential for real-time data analytics determine the amount of intelligence of its products; owing to this, the current research work has made a substantial addition to broadening the findings of prior studies (Schumacher et al., 2019, 2016; Sony and Naik, 2019). The transient nature of customer needs necessitates companies to be prepared to create and produce smart products that will satisfy customer demand while starving to achieve competitive advantage. From that perspective, this study has accepted the hypothesis (H1d) that Smart Products and Operations (SPO) significantly positively impact Industry 4.0 Adoption (I4A). Thus, the key operational competence criteria, including speed, agility, reliability, quality, and cost, are governed by smart operations and products. This study reinforces that the organization must realize the significant role of smart products and operations and continuously build the capabilities to strengthen this concern while transitioning towards I4A.

7.3.5 Industry 4.0 Technologies Relationship with Industry 4.0 Adoption

The essential facet of I4A, the invasion of I4T in an organization, can be used to specify the I4.0 capabilities in manufacturing organizations. The use of 3D printing, IoT, CC, big data analytics, autonomous robotic systems, AR, and VR to increase resource use is necessary for this context for rendering strategies for sustainable development a reality. In this research work, the researcher has found that the hypothesis (H1e) Industry 4.0 Technologies (I4T) significantly positively impact Industry 4.0 Adoption

(I4A) is accepted. Thus, referring to this, the study confirms that to foster I4A, the I4.0 emerging technological changes act as the essential prerequisite for the I4.0 transition. These tools aid in establishing a culture of data-driven, real-time decision-making, which has shown to be a paradigm shift in many companies and has supported the arguments of (S. Kamble et al., 2020; Zhong et al., 2017). Moreover, this research suggests that the industries emphasize broadening their I4.0 compatible technological capabilities to meet the changing market expectation extending the perspective of (Egger and Masood, 2020; Hizam-Hanafiah et al., 2020) to promote I4.0 technologies adoption.

7.3.6 Industry 4.0 Standards Relationship with Industry 4.0 Adoption

Establishing ethics and values in sustainable development is easier when there are supportive global regulations and norms. Additionally, it provides an equal chance for all parties and safeguards weaker players against more substantial companies. In this context, this study has accepted the hypothesis (H1f) that Industry 4.0 Standards (I4S) significantly positively impact Industry 4.0 Adoption (I4A). Hence, pertaining to the responsiveness, safety, and effectiveness of data sharing, it is strongly urged that organizations adopt worldwide standards and protocols to enable real-time communication between intelligent systems, facilitate the exchange of information between companies and their stakeholders, and assist in achieving companies sustainability goal agreeing on the outcomes of (Ghobakhloo, 2021; Tiwari and Khan, 2020). Continuing this, the author reiterates the necessity to establish trustworthy I4S regimens that will expedite the I4A to foster effective interoperability, smart data transfer, and other necessary administration of I4.0 compliant components and their management effortlessly and remotely, facilitating smooth decision-making.

As a result, this study has provided empirical evidence to the assertions of positive relationships between the I4A drivers with I4A is one of the noteworthy additions of this study to the extant literature. The researcher has observed very few studies had evaluated the prospective I4A drivers either considered individually or less in numbers. This study has overcome this and tried to explore, evaluate and validate all possible drivers impacting I4A in one ambit empirically and collectively is one of the significant additions to the upcoming progression of I4.0 literature and practices.

7.3.7 Digital Leadership Relationship with Dynamic Capabilities

Further, an important fact to be noted is that manufacturing is one sector where digital leadership is particularly critical for driving change toward developing DC. Additionally, it creates a new way of thinking about business functions and supply chain management, jeopardizing the market. In light of this circumstance, the acceptance of digital leadership has been recognized as a solution for organizational survival. On this reflection, this study has accepted the hypothesis (H2a) that Digital Leadership (DL) significantly positively impacts Dynamic Capabilities (DC). Hence it is recommended that an organization’s capability be integrated, grown, and redesigned through properly designated digital leadership to detect, capture, and change to embrace new happenings of technological disruptions in the I4.0 implementation era. The result of this study backs up the earlier studies (Jagadisen et al., 2022; Sasmoko et al., 2019; Schoemaker et al., 2018) outcomes on how DC could help an organization perceive market updates by spotting false alarms, recognizing opportunities, averting threats, and creating possibilities to reduce risks. The study suggests this can be achieved through exploring and developing continuous learning about the appropriate digital leadership techniques to keep an eye on the volatile surrounding business environment.

7.3.8 Risks Mitigation Relationship with Dynamic Capabilities

Creating a flawless risk mitigation strategy that takes into account the potential threats and opportunities from internal and external economic, environmental, social, and technical factors can intensify the organization’s DC to capitalize on competitive advantage. On this notion, this study shows that the hypothesis (H2b) Risks Mitigation (RM) significantly positively impacts Dynamic Capabilities (DC) is accepted and asserts the need to explore more insights to gain the intricacies of this relationship to give better justification to this argument. Thus, this study recommends that structuring and managing the operations to identify opportunities and reconfiguring the resources likewise can enhance the DC of an organization. Hence author suggests that recognizing the type of risk and critically designing its mitigation plan can be a stepping stone to improving the company’s DC to move successfully to approach the organization’s sustainability goal.

7.3.9 Supply Chain Agility Relationship with Dynamic Capabilities

In today's fast-paced and rapidly evolving business, offering DC, such as permitting swift supply chain reconfiguration, which manifests the commitments to have significant potential, enabling supply chain agility is a novel idea. This can further improve the DC to provide a competitive edge in the market (Blome et al., 2013). Therefore, supporting this perspective, this study revealed that the hypothesis (H2c) Supply Chain Agility (SCA) significantly positively impacts Dynamic Capabilities (DC). Hence author affirms that the practices should be executed with the supply, manufacturing, demand, and distribution aspects of the firm's supply chain activities taken into consideration as being assumed to be effective, valid, and exhibiting optimum techniques. This will improve the transformation of supply- and demand-side competence into supply chain agility and help build businesses' DC.

7.3.10 Innovation Capabilities Relationship with Dynamic Capabilities

The core element of DC could become strategic management of innovation capabilities. Innovation capabilities include organizational and managerial innovations in addition to new products or services. It typically calls for quick administrative decisions as well as intensive information dissemination, both inside and between organizations and departments. Thus, referring to this, this study shows that the hypothesis (H2d) Innovation Capabilities (IC) significantly positively impacts Dynamic Capabilities (DC). This research proposes that organizations enhance their innovation capacity through structured resource management that fosters synergy and collaboration among various organizational functions to leverage DC. The outcome thus reflects one of the major attempts made by the researcher to contribute to the validation of the studies (Spanuth et al., 2020; Vu, 2020).

7.3.11 Employee Empowerment Relationship with Dynamic Capabilities

When the organizational structure is designed with employee empowerment practices, it encourages employees to work independently and continuously communicate company information and concerns. This allows for flexible teamwork at all company activity levels and, when desired, has the potential to develop the DC of an organization. The empowered employees are capable of making informed decisions regarding the assessment of opportunities and challenges; thus, individual abilities can be delivered more efficiently, and their impact on DC is enhanced through empowerment. On this note, this study indicates that the hypothesis (H2e) Employee. Thus, considering this, the study encourages establishing reformed HR practices and policies emphasizing employee empowerment to enable the authority to address issues that drive employees to put their abilities effectively to complete the assigned work to achieve the intended results. Therefore focusing on employee empowerment offers a space for testing and exploring every individual's capability to manage ambiguous contextual issues and encourages them to become problem-solver, which can assist boost their confidence and further ascertains the conclusions from the research (Motamarri et al., 2020; Müller et al., 2014; Rachel and Tallott, 2016).

Therefore, the study insists on the notable contribution made by this research to the prior studies as it has provided empirical support to the arguments of positive relationships between the DC drivers and DC. The study has discovered that relatively little research had assessed the potential DC drivers separately or not enough to gain in-depth insights into these relationships. Thus, the current investigation surmounted this by attempting to empirically investigate, appraise, and validate all potential drivers affecting DC across one vicinity. Collectively, these efforts constitute a substantial contribution to the advancement of I4.0 literature and practices to empower the DC of an organization.

7.3.12 Innovation in Green Processes Relationship with Circular Economy Practices

CEPs are likely to be supported by manufacturing processes that involve green design principles in the innovation process. Additionally, firms are forced to develop innovations in green processes to properly utilize their resources and minimize waste because their customers prefer to choose green products. On this notion, this study reflects that the hypothesis (H3a) Innovation in Green Processes (IGP) significantly positively impacts Circular Economy Practices (CEP) is accepted. Addressing this, if the innovation focuses on everything from the beginning of green procurement to the final delivery of the product to the customers and beyond that, after-sales service can help the organization lay the groundwork for promoting CEPs to leverage its competitive advantage. Further, it is believed that this can be made possible by implementing advanced green innovation techniques in greening the business processes. Thus the author proposes that prioritizing investment planning, integrating recycling of waste products in manufacturing activities, and well-organized execution of techniques in innovating green processes and knowledge management will encourage the CEPs to gain a green image of the business and long-term strategic partnerships with customers validated and expanded the findings of the research (Alhawari et al., 2021; Khan et al., 2022; Schiederig et al., 2012).

7.3.13 Circular Dynamic Environment Relationship with Circular Economy Practices

Although a circular dynamic environment has been projected to empower CEP, establishing a CDE is still not easy since it involves a lot of uncertainties. These concerns arise from customers, technological improvements, and external environmental elements, including competitive pressure and inconsistency in evolving government laws, norms, and legislation. However, all these concerns are beyond organizational control and can still be handled smartly. Thus to address this persuasion, this study shows the hypothesis (H3b) Circular Dynamic Environment (CDE) significantly positively impacts Circular Economy Practices (CEP) is rejected. Therefore, the author posits that the abovementioned issues can be effectively addressed by embracing intelligent technological solutions and enhancing organizations' ability to make real-time decisions. Adding to this, pursuing customer awareness campaigns to influence customers through ongoing interaction and regular updating. Thus, differentiating the company's image from counterparts and thinking innovatively beyond its capabilities will assist improve the DCs of the organization and growing CDE without putting much effort. Thus, this reflects that no significant relationship between CDE and CEP is confirmed. As very few studies have noticed these concerns (Khan et al., 2020a) , hence this study's findings can be one of the foundational studies to uncover more insights into this relationship.

7.3.14 Investment Recovery Relationship with Circular Economy Practices

Surplus, end-of-life, and old resources conversion into strategies to create returns through reverse logistics incorporating proper recovery or secure disposal of these resources can help recover investments. This can also be made possible by receiving the returned product from multiple locations, extracting valuable components derived from recycled materials, and marketing the product that has been reconditioned at the remanufacturing level. Thus the outcomes from IR practices enable optimizing material and energy use, recovering utility from waste, and transforming non-renewable to biodegradable materials consumption to promote CEP (Bocken et al., 2016; Edwin Cheng et al., 2021). On this impression, this study's findings show the hypothesis (H3c) that Investment Recovery (IR) significantly positively impacts Circular Economy Practices (CEP) is accepted. Hence this study recommends that companies be inspired and guided to customize existing IR practices through continuous research and development. This customization could focus on using biodegradable, recyclable, reusable materials and products to gain maximum economic and environmental competitive advantage. By doing this, companies will harness the best of the CEP, which is the study's substantial addition to the body of existing literature.

As this research work has offered empirical evidence to support the claims of positive associations between the CEP drivers and CEP, this study advocates the important contribution made by this investigation to the recent research. The study found that these putative CEP drivers have either been evaluated separately in relatively little literature or insufficiently to provide detailed insights into these linkages. Hence, the current research has ameliorated this by considering all relevant drivers affecting CEP in one platform. Also, methodologically investigating, assessing, and validating their significance, concluding no effect of CDE on CEP, has demonstrated a new aspect of the CEP driver to explore further. These initiatives add significantly to the development of CEP literature to strengthen the CEP of an organization.

7.3.15 Industry 4.0 adoption Relationship with Dynamic Capabilities

I4A focuses mainly on an organization's digital transformation that can successfully drive DC advancements (Sasmoko et al., 2019). Still, very few studies have explored this context, emphasizing the reverse relationship (Warner and Wäger, 2019); in light of this, this study has given the breakthrough to the idea of digging into the relationship between I4A and DC. Hence, broadening this idea, this study reinforces that the hypothesis (H4) Industry 4.0 Adoption (I4A) significantly positively impacts Dynamic Capabilities (DC) is accepted. On this note, this study highlights that more emphasis should be given to promoting the DCs to extract the maximum capabilities of I4A. These can be attained by empowering the I4.0 resources like IT infrastructure, employees' continuous motivation, and training to become digital savvy to leverage real-time decision-making and investigate more on other prominent I4.0 compliant resources. The study finding shows the positive relationship reflects that taking care of these concerns makes the way forward for the company much smoother for achieving a competitive advantage.

7.3.16 Dynamic Capabilities Relationship with Circular Economy Practices

Successful enforcement of competencies in developing the reuse, recycle, refurbish, remanufacture, and waste reduction practices in the manufacturing operations can bolster the environmental sustainability capabilities, further driving the CEP (Scarpellini et al., 2020a). In putting forward this notion, the findings of this study reflect that the hypothesis (H5) Dynamic Capabilities (DC) significantly positively impact Circular Economy Practices (CEP) is accepted. Therefore, this study proposes a solution like minimizing environmental degradation by ensuring waste reduction. Managing These activities contribute to limiting pollution, reducing the use of emission-causing substances replaced with alternatives or substitutes, and encouraging innovation and efficient resource use. Proper management and deployment of energy, water, and raw materials replaced with alternative smart materials can act as the foundational base for strengthening the environmental DC and enabling companies' reconfiguration capabilities, which ultimately can trigger the progression of CEP, expanding the assertions made by the research (Scarpellini et al., 2020a) demonstrating its importance to the worth taking into account in practical situations.

7.3.17 Circular Economy Practices Relationship with Sustainable Organizational Performance

According to Silva et al. (2019), CEP can improve economic performance by encouraging product quality and resilience throughout manufacturing and focusing on maintenance and service to help enhance the product's usable life and boost brand perception. Additionally, the CEP impacted ecological sustainability regarding the prudent use of natural resources to prevent their depletion and environmental deterioration. Similar to this, the CEP has the potential to improve social performance by promoting the use of biodegradable and environmentally friendly materials that are smart and safe for use, eliminating the sources of health problems for employees, and offering green products that gain the trust of customers. On this notion, this research shows that the hypothesis (H6) that Circular Economy Practices (CEP) significantly positively impact Sustainable Organizational Performance (SOP) is accepted. Thus, this study strongly encourages taking the relative measure for continuous evaluation of environmental performance indicators, effective risk and challenges management, and alignment of company policy, vision, and mission with the company goals, considering the corporate social responsibility concern. Also, providing a sustainable platform for knowledge and information management, strategic short-term and long-term investment plans, and facilitating continuous training and technological upgradation plans will help companies empower CEP and prepare to become competitive to achieve SOP.

7.3.18 Industry 4.0 Adoption Relationship with Sustainable Organizational Performance

Companies realized that deceptive vision, policies, and complex digital infrastructure planning might cause the breakdown of the most cutting-edge business plan. The comprehensive digitization that will support the I4A goal of the organization should be accomplished with long-term prospects in sight. For that, it is crucial to have visionary leaders who can thoroughly comprehend the digital solutions based on IT that can connect stakeholders. Thus, the relationship between I4A and SOP cannot be overlooked to achieve companies' sustainability goals. On this front, this study demonstrates that the hypothesis (H7) Industry 4.0 Adoption (I4A) significantly positively impacts Sustainable Organizational Performance (SOP) is accepted. Thus, on this stake, we recommend that the organizations strive to lower expenses, effectively manage waste, and consistently seek to increase employee satisfaction, quality of products, protection of the environment, e-waste management, and efficient resource utilization. This can be accomplished by using data-driven production processes and real-time value chain monitoring. Further, it can be extended by deploying a self-coordinated and configurated decision-making system facilitating the communication among connected devices, humans, and machines, and the remote and secured access of information through data analytics leading to gaining valuable insights which further can capitalize SOP. Thus this outcome supports the claims of the research (Harikannan et al., 2020).

7.3.19 Synergistic Integration of Dynamic Capabilities and Circular Economy Practices Relationship with Sustainable Organizational Performance

The outcome of this research revealed an interesting relationship among the four primary constructs (I4A, DC, CEP, and SOP). I4A's direct impact on SOP is already discussed, and supporting evidence is provided, but the one crucial observation described here is beyond that. The unique dimension of the relationship is the positively significant mediating role of DC and CEP (H8) on the I4A and SOP's indirect relationship, which is found to be stronger than the direct relationship. It is quite reasonable to accept the empirical evidence that fully supports the synergic effect of DC and CEP significantly influencing the indirect relationship between the I4A and SOP. The study's noteworthy findings identify DC and CEP as critical drivers; its mediation accelerates the I4A impact on SOP and strengthens the claim that DC and CEP provide a strong complementary effect on this indirect relationship compared to the direct one. Thus, this study reveals that maximizing the impact of I4A on SOP, the role of DC and CEP must be recognized for sensing, seizing, and reconfiguring possible opportunities and threats. Thus, DC and CEP's role in developing strategic policies for I4A to achieve SOP is beyond doubt. This study suggests that companies must integrate DC and CEP while developing impactful concrete strategies and policies to accomplish the goal of SOP. DC and CEP intervention has the capability to unlock I4A's full potential, leading to improvements in resource productivity and efficiency. Thus, our study revealed that developing DC would empower the confidence in strengthening CEP and help in the smooth progression of I4A. Additionally, organizations attempting to improve digital features and functionality, smart product design, effective and efficient customer management, product lifecycle monitoring, optimal product performance, product up-grading, ergonomic design work environments, and waste elimination can expedite the I4A. This leads to boosting the SOP and acquiring a long-term competitive advantage over others if integrated with DC and CEP.

Hence this study is the pioneer in establishing the critical role of DC and CEP in expediting the impact of I4A on SOP. The researcher would like to confirm that there is no such study has been undertaken in the past. This study's direct and robust evidence makes it unique and the first of its kind. The researcher considers this a major and path-breaking contribution to the new knowledge, allowing policymakers to think of introducing catalysts like DC and CEP to amplify SOP. Further, the developed mathematical model to predict SOP will add substantially to the extant corpus of knowledge. The next section provides a deeper understanding of our study's theoretical and practical implications.

7.4 Theoretical Implications of the Study

The research approach adopted and findings of exploratory study 1, **Chapter 4** can guide researchers and academics in the manufacturing industry on more effective ways to boost productivity in the I4.0 setting through the careful monitoring of I4.0 KPIs and KSFs. The findings supported the earlier study adds value to the corpus of extant literature. Further, the findings of exploratory study 2, **Chapter 5** researchers studying I4A in the manufacturing sector will benefit from the adeptly developed model for the I4.0 risks assessment framework. Through careful management of I4.0 KPIs and I4.0 risks, companies can offer improved processes and approaches to boost efficiency within the I4.0 ecosystem. The study makes a significant contribution to the body of new information because its outcomes are well-supported and offer rationale based on earlier research. The explanations below outline the specific theoretical implications of the final research problem.

The acquisition of I4.0 has triggered several advancements in the Indian manufacturing sector. Most organizations have started it, and many more are currently implementing it slowly and assessing its viability to comprehend its determinants of success and potential uncertainties (G. Yadav et al., 2020). The present investigation, carried out in India, has successfully addressed the demands for fundamental data-based study in the I4.0 domain, with a particular emphasis on rationalizing the complexity of I4A by giving empirical evidence and reinforcement for previous studies. This research has significantly added to new knowledge by reflecting on theoretical aspects. The observations through comprehensive SLR reflects that the earlier studies only considered I4.0 barriers, I4A, and operational performance (Chauhan et al., 2021), I4T and lean manufacturing impacting SOP (S. Kamble et al., 2020), I4A and green supply chain management (Ghadge et al., 2022), innovations and CE (Suchek et al., 2021), DC impacting CE and I4.0 risks framework (Birkel et al., 2019), fully ignored the linkage between I4A, DC, CEP, and SOP. Thus, it confirms that this is a unique study to identify the connection between I4A, DC, CEP, and SOP. It also examines the critical association between all crucial drivers for I4A, DC, and CEP, which will aid decision-makers in preparing organizations to migrate towards I4A and engage with SOP.

Considering the use of reliable sample size, the number of constructs, and the sufficient number of measuring indicators that ascertain the study's theoretical distinctiveness. The study's uniqueness also stems from analyzing each item's function while considering many potential hypotheses. This discrimination will undoubtedly entice and complement other industries to adopt I4.0 firmly. The complementary mediating effect of DC and CEP in the relationship between I4A and SOP was determined in this study, showing the way forward for the researchers to deploy a systematic approach to promoting DC and CEP. Thus, emphasizing effective resource management, pervasive leadership, the delegation of authority, data handling, information management, dealing with cybersecurity issues, focusing on innovation culture, and managing ecological concerns can successfully stimulate the organizations towards gaining SOP. Therefore, this improves awareness, productivity, flexibility, speed, quality, and reliability, considering energy, cost, time, and resource savings.

Also, the study has demonstrated the PLS-SEM capability to address the significant research issues raised by this investigation. The researcher has discovered that the unique methodological characteristics of PLS-SEM make it ideal for estimating the comprehensive structure (Jacoby, 1978), which is considered in the present study and perfectly suits the current application. Academics and researchers can use the findings of this study to create a framework that incorporates DC improvement tactics and increasing CEPs while implementing I4.0 projects. The investigation will further uncover I4A's unnoticed facets will be the addition to the corpus of novel knowledge. The verified set generated for the measurement items presented in this study for the drivers of I4A, DC, and CEP, I4A, DC, CEP, and SOP constitutes one of the most significant advancements in the theory of the I4.0 horizon about the Indian manufacturing industry. The measurement tools employed in this study have undergone statistical validation for construct reliability and discriminant validity, as well as pilot testing, guaranteeing that they may be applied to new studies with minimal to no modification. Furthermore, this study asserts that the novel method of considering contingency theory with DCV utilized in this study offers a robust platform for maintaining the credibility of the findings and the multitude of possible applications. This diligent investigation has the potential to have a positive influence on the method of determining decisions for the best use of resources, especially funds, time, technology, talent management, and materials, for the successful harnessing of DC and CEP to accelerate the adoption of I4.0 and achieve sustainability in organizational operations. When assimilating technology solutions and putting advancements into practice in this dynamic environment, it is advised to maintain a close eye on business and industry circumstances to grasp customer expectations. This research proposes a strong foundation for establishing organized decision-making that will lead to sustainability by defining, categorizing, and analyzing the significance of key constructs I4A, DC, CEP, and SOP. Consequently, the research will benefit from designing a tailored strategy according to the requirements and capabilities of the organization and avoiding the risks of cluelessly replicating competitors. Interesting and thoughtful direct and indirect links between the major constructs were found in this study, bringing new prospects for achieving organizational sustainability. It has been determined that the mediating mechanism of DC and CEP between I4A and SOP is extremely important and deserves to be addressed cautiously. This study provides an avenue for academicians and researchers to further explore the association between distinctive I4A traits and other DC and CEP-related attributes. Also, the developed regression equation to predict SOP will guide the researchers to quantify the effect of the decision variables.

7.5 Practical Implications of the study

The findings of exploratory case study 1, **Chapter 4,** can serve as a foundation for easing the I4A and assisting practitioners and managers of manufacturing firms in efficiently managing their capabilities and resources to maximize sustainable development through effective deliberations and handling of I4.0 KSFs and KPIs.

The results of exploratory research 2, **Chapter 5** indicate that practitioners and professionals can improve their skills and abilities by adopting I4.0 standards and raising their understanding of technological challenges and risk-related problems brought on by threats to information security. Managers should exercise caution when choosing third-party service providers to host and operationalize company data. One of a company's most crucial resources is its workforce. Managers can succeed in I4.0 initiatives by encouraging a collaborative, cooperative atmosphere by altering their attitudes regarding opposition to the new working culture and developing new skills and ways of thinking. According to this research on the importance of social risks for I4.0, the transition will direct managers in their efforts to persuade and inspire their employees by raising awareness. The following explanations detail the precise practical implications of the final research problem.

Especially for managers and practitioners engaged in I4.0 endeavors, this research has offered some remarkable insights for ensuring a sustainable business. According to the outcomes of this investigation, Indian manufacturing companies are stepping up I4A passionately. Particularly, to sustain the situation during and after the Covid-19 pandemic outbreak, I4A has been expedited and is at different deployment stages. The significant drivers of I4A are identified to be capital investments, stakeholders as employees and customers, organizational strategies, smart products and operations, I4.0 technologies, and I4.0 standards. Thus, the top managers and company executives should optimize these resources to create distinctive DC for the organizations. They should also dwell on advancing I4.0's technological foundation, well-thought-out I4S, intelligent products, and operations that emerge in real-time and align with I4.0 prerequisites.

Additionally, they ought to improve the management of long-term organizational plans and I4.0 financial investment strategies. Besides this, assimilating data-driven solutions enabling customers to connect with the company can assist in I4A and should be designed accordingly. Other aspects to consider when pursuing I4A include encouraging the employees to embrace it enthusiastically and establishing trust. This indicates that to attain optimum performance, prevail over fierce competition within and outside the organization, and promote innovative prospects for long-term growth and progress, managers should embrace distinctive and imaginative combinations of their inherent capabilities. With the various initiatives of the government of India like skill India, Make in India, Samarth Bharat Udyog 4.0, and Digital India, making fast progress with its digitalization programs. Thus, India will soon be heading toward the I4A motive in the manufacturing sector; this will inspire the top management and administration of Indian manufacturing industries to embrace it willingly.

It is found that profound digital leadership and risk reduction through incorporating risk mitigation practices, achieving agility in the supply chain, and promoting employee empowerment culture enhance companies' DC. A fascinating outcome that should be considered is a well-planned I4A facilitates the organizational DC. Thus, we recommend that the managers and policymakers reckon about prudent investment strategies in technological, operational, and infrastructural innovations, and strengthen digital leadership to become techno-savvy, remain updated, and be resilient to respond to a dynamic environment. Similarly, recognizing and analyzing the risks in the company's various functions and devising their mitigation policies emphasizes the company's capacity to swiftly modify its strategy concerning purchasing, inventory control, and delivery of the product to accommodate supply chain agility. And the continuous motivation and empowerment of employees for problem-solving through authority delegation can successfully promote companies' DC, makes it easy, and can execute successfully by embracing the I4A.

This study also makes a significant contribution by revealing how innovation in green processes and investment recovery with CEP can help managers and policymakers. This will stimulate them to think thoughtfully about how to deal with environmental protection, waste recycling, and energy conservation concerns to promote green products and safeguard the integrity of the ecological system, which is undoubtedly the most important concern in the present situation. Additional insights are given by the study that the CDE does not significantly impact CEP. On this note, this study would recommend that managers and policymakers use technological solutions to harness their capabilities to engage with customers, updating them continuously through awareness campaigns and keeping their interest in company products by maintaining healthy customer relationships. Thus, with hardly putting much effort, boosting the organization's DCs and handling CDE may be accomplished by differentiating the company from competitors and thinking out of the box.

One of this study's intriguing results is the direct influence of I4A on SOP. The link between I4A and SOP is mediated through DC, and CEP has provided insightful information about the critical role of DC and CEP in realizing SOP, leading to the conclusion that the indirect relationship is more substantial. So, to achieve the ultimate objective of SOP, this study proposes that company managers and practitioners consider making an effort to integrate DC and CEP even while creating effective, tangible strategies and policies. The I4A can be fully unleashed with the help of DC and CEP interference, which will boost resource effectiveness and productivity. Thus, it became clear from this investigation that establishing DC would make a massive difference in fortifying CEP and facilitating the I4A for advancing towards SOP. Therefore, the empirical evidence offered by this study will guide the managers and policymakers in addressing the dynamic nature of business by balancing the contingencies of the company to leverage competitive advantage when dealing with I4A, DC, CEP, and SOP meticulously.

7.6 Conclusions

This study aims to investigate the role of I4A in evaluating the SOP. Thus, to address this issue, the scientific and well-supported literature backed up methodology followed from conducting quantitative and qualitative LR, including SLR and further designing case studies to reach the final research problem, has increased the credibility of the findings and the developed roadmap to conduct such type of empirical research is the most noteworthy contribution of this research.

In exploratory study 1, **Chapter 4,** with the EDAS technique's deliberation, In order to deploy I4.0, the study has devised a strategy that prioritizes the most crucial KSFs. This study's findings showed that the internet network infrastructure is the most important KSF in determining the success of I4.0. This work contributes to the knowledge base in a number of ways by establishing a model for KSF evaluation for the effective execution of I4.0. This research has developed the foundation to help managers, academics, researchers, and policymakers establish implementation schedules for I4.0 in addition to offering a distinctive viewpoint. The findings can be used as a reference to help all industries that recently announced plans to adopt I4.0 structure their plans and strategies for I4.0 KSFs and KPIs.

In exploratory study 2, **Chapter 5,** due to cost, technology, and workforce management impediments, it might not be feasible for every industry to digitize their entire organization at once to comply with I4.0. While it initially appears profitable and alluring, there are a lot of risks and difficulties lurking behind the shell. The numerous risks and the influencing KPIs to the risks may obstruct the overall goal of implementing I4.0 if they are not identified beforehand. As was discovered in the literature review, numerous risks have been examined to determine how they will affect the implementation of I4.0. However, only a small number of studies have experimentally examined the causal link between the KPIs for risk implementation and risk prioritization. Out of all the KPIs, this study's findings show that cost and information security require the most attention. The list of alternatives determined that the technological and social risks were the most pressing and required immediate attention. The conclusions of the final research problem are explained in detail in the following sections.

Manufacturing businesses are scrambling to attain SOP to satisfy growing customer requirements and competitive pressure. Although DC and CEP synergistic roles are crucial for driving I4A, previous research rarely gives them the recognition they crave. The primary objective of the present study is to determine the direct influence of I4A on SOP and the indirect impact via DC and CEP. The researcher has examined how DC and CEP mediated the association between I4A and SOP. Furthermore, the influence of I4A, DC, and CEP success factors and their connection.

In this exceptional study, which is based on contingency and DCV theory, the linkage between I4A, DC, CEP, and SOP is empirically confirmed. The study's main finding was that I4A is positively associated with I4A drivers such as capital investments, stakeholders as employees and customers, organizational strategies, smart products and operations, I4.0 technologies, and I4.0 standards. Furthermore, positive relationships between DC and digital leadership were observed, including risk mitigation, supply chain agility, innovation capabilities, and employee empowerment. Moreover, it is confirmed that there is a positive relationship between I4A and DC, DC and CEP, CEP and SOP, and I4A and SOP. Over and above, the study also produced an interesting finding, such as DC and CEP integration is a pivotal mediating construct that positively mediates the relationship between I4A and SOP.

The relationship between the four main constructs, I4A, DC, CEP, and SOP, was demonstrated through the model. This study's findings confirm that a manufacturing organization can implement the I4.0 paradigm with the amalgamation of I4A, DC, CEP, and SOP. Nevertheless, each of the four has a tremendous ability to support the company in attaining sustainability, viability, and competitive advantage. Therefore, the findings are noteworthy and practicable for dealing with the dynamic and unpredictable business environment. A critical finding of this study that earlier studies overlooked is the direction and strength of the link between I4A, DC, CEP, and SOP. This research was performed in Indian manufacturing firms since there are differences between these companies' degrees of digitization and their desire to completely or partially pursue the I4.0 agenda. It is crucial to mention that the researcher also encountered companies proactively embracing I4.0 practices at staggering speeds, but it is anticipated that this would escalate soon.

7.7 Limitations and Future Scope

There are also certain limitations of the exploratory case study 1, **Chapter 4**. This research is done within the framework of Indian manufacturing industries. The same study might be carried out for other nations and businesses to acquire additional insights into I4.0. Further I4.0 dimensions would emerge from further research into incorporating additional KSFs and KPIs into the existing list. The EDAS approach was used to rank the KSFs. Thus, another MCDM technique can be used to validate the results. Since expert judgments are the focus of the analysis and expert opinions can vary from person to person, the experts' biases may impact the study's findings.

There are also certain limitations of the exploratory case study 2, **Chapter 5,** as this I4.0 KPI-based I4.0 risks prioritization study is conducted in Indian pretext. A similar study should be undertaken in other developed nations that have previously adopted I4.0 in their businesses to uncover further aspects of how I4.0 transformation may affect KPIs and potential risks. Additionally, this study advises employing an empirical research design approach and confirming the results using a survey-based methodology. Furthermore, using structural equation modeling tools and other multicriteria decision-making methods may yield more precise results. The next sections provide a detailed explanation of the final research problem's limitations.

Although the research is distinctive and original, several limitations cannot be underestimated. In this context, the results obtained from this study must be checked by taking into account the most recent trends in present circumstances to ensure accuracy, as the Indian manufacturing companies are at different levels of I4A. If research of a synonymous nature is administered in developed countries, it would assist in understanding the other side of the spectrum.

The research's other limitations include the representative sample and sample characteristics. Thus, the multiple sample groups may provide more breakthroughs of information about I4A, DC, CEP, and SOP. The longitudinal research design can be used to make inferences regarding the evolving nature of drivers influencing I4A, DC, and CEP and then further affecting the relationship between I4A and SOP, even if this study uses a cross-sectional research technique. New variables may also be included on the list of essential drivers that drive the I4A particular socioeconomic-ecological contexts, depending on their potential significance and background, and they may capture the interest of researchers and practitioners because of the growing demand for sustainable business models.

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Annexure: 1
Survey Questionnaire

Name of the respondent (optional):

Company's name and address:

Email address:

Part A: General Information

Kindly click on the appropriate option:

1) What is the designation you hold in your organization?

- ○ Proprietor/COO/CEO/CFO/MD
- ○ General Manager/ Director/ Head of Business unit
- ○ Head of Department
- ○ Senior Manager/ Manager
- ○ Consultant / Data Analyst
- ○ Engineer

2) What is your educational qualification?

- ○ PhD/ DBM
- ○ Masters/ Postgraduate Diploma
- ○ Graduate
- ○ Diploma

3) How many years of experience do you hold (in years)?

- ◉ More than 40
- ○ 31 to 40
- ○ 21 to 30
- ○ Less than 10

4) How will you classify your organization?

- ○ Automotive
- ○ Metals and machinery
- ○ Electrical/Electronic equipment and appliances
- ○ Energy (Generation, Distribution and Marketing)Services
- ○ IT (Hardware and Software)
- ○ Furniture Manufacturing
- ○ Textile

- Food and Beverage
- Defense/Aerospace equipment manufacturing
- Engineering Services
- Pharma Companies
- Chemical Industry
- Rubber / Plastic Manufacturing
- Refrigeration and Airconditioning Manufacturing
- Paper and Packaging manufacturing
- Other Manufacturing and Production

5) How will you classify the ownership of your organization?

- Multinational
- Private
- Public Sector

6) How many employees currently working in your organization?

- More than 1000
- 801<=1000
- 601<=800
- 401<=600
- 201<=400
- 51<=200
- <=50

7) What is the approximate annual turnover of your organization (In crore Indian rupees)?

- More than 500 Crore
- 250 to 500 Crore
- 75 to 250 Crore
- 10 to 75 Crore
- 5 to 10 Crore

Part B: Main Questionnaire

Please choose the option that best describes how much you agree or disagrees with each of the following statement.

(Kindly rate on 5 points Likert scale: consider 1= "Strongly disagree," 2: "Disagree," 3= "Neutral,";4= "Agree," 5= "Strongly Agree").

Main Construct	**Sub-construct**	**New Code**	**Questionnaire**	**1**	**2**	**3**	**4**	**5**
Industry 4.0 Adoption (I4A)		I4A1	My organization's digitization policies have led to cyber-physical integration of production lines and more flexibility and collaboration among employees.					
		I4A2	My organization uses emerging technologies to harness operational excellence by reducing waste and increasing resource efficiency and production flexibility.					
		I4A3	My organization has clearly established the Industry 4.0 vision in most business functionalities.					
	Capital Investment (CI)	I4ACI1	My organization's financial investment decisions are guided by an in-depth cost-benefit analysis of the proposed Industry 4.0 projects and technology.					
		I4ACI2	My organization has strategically invested in Industry 4.0 transformation projects.					
		I4ACI3	My organization's Industry 4.0-related investments are generating a significant return on investment.					
	Organizational Strategies (OS)	I4AOS1	My organizational strategies motivate employees to be competitive by adopting Industry 4.0 innovative ways of doing business.					

Main Construct	Sub-construct	New Code	Questionnaire	1	2	3	4	5
		I4AOS2	My organization has thoughtfully adopted Industry 4.0 promoting methods and means to strengthen the I4.0 vision and mission.					
		I4AOS3	My organization's strategies include workforce upskilling and empowerment, mitigating social risk, and increasing outcomes.					
	Smart Product and Operations (SPO)	I4ASPO1	My organization's smart products and operations can share data and data analytics outcomes with the control centers.					
		I4ASPO2	My organization's smart operations allow fast product customization to alter the performance using digital tools in demanding conditions.					
		I4ASPO3	My organization's products facilitate product monitoring and control remotely through secured access.					
	Stakeholders as Employees and Customers (SEC)	I4ASEC1	My organization promotes employee and customer involvement by providing continuous training and education in collaboration.					
		I4ASEC2	My organization promotes customer involvement by deploying/deputing customer-focused data scientists to capture timely inputs.					
		I4ASEC3	My organization promotes employee and customer					

Main Construct	Sub-construct	New Code	Questionnaire	1	2	3	4	5
			involvement by nurturing and creating a culture of new idea generation and innovations, promoting a people-centric approach.					
		I4ASEC4	My organization promotes an effective and efficient relationship with the supplier for better collaboration and coordination.					
	Industry 4.0 Technologies (I4T)	I4AI4T1	My organization uses the Internet of things to communicate and connect with machines, sensors, actuators, network devices, and people with the objective of supporting enhanced performance.					
		I4AI4T2	My organization uses Intelligent Automation to add value and excellence to business processes to become a smart organization.					
		I4AI4T3	My organization uses Big data analytics to promote the seamless exchange of data to all the stakeholders, thereby impacting real-time decisions.					
		I4AI4T4	My organization promotes using Virtual Reality, Augmented Reality, and Cloud Computing for highly efficient and effective resource utilization and protection of the environment.					
	Industry 4.0 Standards (I4S)	I4AI4S1	My organization has a proven framework for developing and					

Main Construct	Sub-construct	New Code	Questionnaire	1	2	3	4	5
			implementing the I4.0 standards.					
		I4AI4S2	My organization is implementing the I4.0 standards in managing cyber security and excellence in production.					
Dynamic Capabilities (DC)		DC1	My organization has recognized, rectified, and reconfigured critical business processes to meet market dynamics and remain competitive.					
		DC2	My organization has established a data-based decision-making system to withstand complex market and trade dynamics.					
		DC3	My organization uses a dynamic resource allocation strategy to withstand complex market and trade dynamics.					
		DC4	My organization uses dashboard applications on communication devices (e.g., smartphones and computers) for effective and dynamic decision-making.					
	Digital Leadership (DL)	DCDL1	My organization's leadership has the digital competencies, capacities, and capabilities to meet the speed, flexibility, and reliability in decision-making.					
		DCDL2	My organization's digital leadership promotes research and innovation needed for constantly generating					

Main Construct	**Sub-construct**	**New Code**	**Questionnaire**	**1**	**2**	**3**	**4**	**5**
			new ideas, products, and services.					
		DCDL3	My organization's digital leadership promotes data-based decision-making, improving the decisions' precision, accuracy and reliability, and relevance to the prevailing situation.					
	Innovation Capabilities (IC)	DCIC1	My organization has an active and engaging Research and Innovation support system which ensures the organization's capability to be innovative and a pioneer in the market.					
		DCIC2	My organization's Research and innovation practices provide large scope for new product and service development using creative and market intelligence.					
		DCIC3	My organization's Research and innovation practices train suppliers to be innovative in anticipating customer and business needs.					
	Risks Mitigation (RM)	DCRM1	My organization has a clear and engaging vision and mission, which contributes highly to risk mitigation, empowering and guiding the workforce toward meeting organizational goals.					
		DCRM2	My organization has a policy of reallocating company infrastructure					

Main Construct	Sub-construct	New Code	Questionnaire	1	2	3	4	5
			to mitigate risks of meeting the dynamic demand of the volatile market by mitigating the risk of missing business opportunities.					
		DCRM3	My organization's strategies allow the change in business model to comply with Circular Economy and Industry 4.0 to mitigate the risks of being uncompetitive and out of demand in the market.					
	Supply Chain Agility (SCA)	DCSCA1	My organization promotes dynamic connectivity among suppliers and customers, ensuring seamless and real-time information exchange.					
		DCSCA2	My organization's crisis management teams form an integral part of the supply chain, which develops contingency plans to keep the functionalities up and running at all times.					
		DCSCA3	My organization's supply chain is reconfigurable and self-organizing so as to sustain in volatile and critical market conditions.					
	Employee Empowerment (EE)	DCEE1	My organization's knowledge management policies allow timely and secured access to employees for sharing required information.					
		DCEE2	My organization provides equal opportunities to all					

Main Construct	**Sub-construct**	**New Code**	**Questionnaire**	**1**	**2**	**3**	**4**	**5**
			employees for upskilling and training in respective domain areas.					
		DCEE3	My organization continuously facilitates employees to explore opportunities for adopting updated technology to maintain an upper edge in the industry.					
		DCEE4	My organization inspires employees to explore opportunities to apply multiple skills at the workplace, thereby increasing the workforce's flexibility and utility.					
Circular Economy Practices (CEP)		CEP1	My organization's circular economy practices proactively promote energy saving and recycling to convert waste into a valuable input for production.					
		CEP2	My organization's circular economy practices promote renewable, recyclable, or biodegradable inputs to reduce environmental hazards.					
		CEP3	My organization's circular economy practices promote products designed for reuse, recycling, and recovery of materials or components and ensure suppliers meet these environmental objectives.					
	Innovations in Green Process (IGP)	CEPIGP1	My organization's green process innovation practices promote					

Main Construct	Sub-construct	New Code	Questionnaire	1	2	3	4	5
			environmentally friendly processes and technologies to manufacture environmentally friendly products.					
		CEPIGP2	My organization's green process innovation practices promote the use of the least polluting and energy-consuming materials for environment-friendly manufacturing products.					
		CEPIGP3	My organization’s green process innovation practices emphasize the criteria of recycling, reuse, and decomposability of the product at the design stages to ensure the product's environmental friendliness.					
	Circular Dynamic Environment (CDE)	CEPCDE1	My organization believes that the customers are aware and receptive to manufactured products, considering waste management principles environmentally friendly.					
		CEPCDE2	My organization believes that technological advancements create prospects for circular economy implementation.					
		CEPCDE3	My organization believes that circular economy-based products are					

Main Construct	Sub-construct	New Code	Questionnaire	1	2	3	4	5
			competitive and in high demand					
	Investment Recovery (IR)	CEPIR1	My organization's investment recovery practices promote the sale of surplus inventories and scrap to raise capital and reduce overheads.					
		CEPIR2	My organization's investment recovery practices promote value generation through the recycling of used products/material					
Sustainable Organisational Performance (SOP)		SOP1	My organization has reduced the costs of production and improved productivity.					
		SOP2	My organization has controlled toxic and polluting waste output, contributing to environmental protection.					
		SOP3	My organization has optimized resource use by reducing coal, energy, and water use.					
		SOP4	My organization has experienced an increase in job satisfaction among the employees and trust in the community.					
		SOP5	My organization has experienced increased customer satisfaction by improving product quality and customer loyalty.					
		SOP6	My organization has experienced an increased ability to meet environmental protection standards after continuous					

Main Construct	Sub-construct	New Code	Questionnaire	1	2	3	4	5
			employee training and skills development.					
		SOP7	My organization has improved its waste management ability after implementing economic practices.					
		SOP8	My organization has improved on work safety-related performance criteria to be people-oriented and caring.					

R.A.Gadekar

Mrs. Rimalini Ashish Gadekar

(Signature of Candidate)

Date: 04 Nov.2022

Bijan Sarkar 04 Nov 22

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