ASSESSING INDUSTRY 4.0 IN PRODUCTION PLANNING AND CONTROL- A CASE OF INDIAN AUTOMOBILE INDUSTRY

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2025

DECLARATION

I hereby declare that the presented work in the thesis entitled *"ASSESSING INDUSTRY 4.0 IN PRODUCTION PLANNING AND CONTROL- A CASE OF INDIAN AUTOMOBILE INUSTRY"* in fulfilment of degree of **Doctor of Philosophy (Ph.D.)** is an outcome of the research work carried out by me under the supervision of **Dr. Mohd. Nasir**, working as an Asst. Professor at Mittal School of Business, Lovely Professional University, Punjab, India. In keeping with general practice of reporting scientific observations, due acknowledgements have been made whenever work described here has been based on findings of another investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.

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CERTIFICATE

This is to certify that the work reported in the Ph.D. thesis entitled "ASSESSING INDUSTRY 4.0 IN PRODUCTION PLANNING AND CONTROL- A CASE OF INDIAN AUTOMOBILE INUSTRY" submitted in fulfillment of the requirement for the award of degree of **Doctor of Philosophy (Ph.D.)** in the Management, is a research work carried out by Mr. Rahul Kumar Singh, 42000223, is a bonafide record of his/her original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.

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ABSTRACT

The primary aim of this thesis is to identify the readiness factors, barriers, and catalysts involved in the integration of Industry 4.0 into production planning and control. These factors will be analyzed based on their importance and interconnections using methods such as the Delphi study, Fuzzy COPRAS, and Fuzzy Best Worst Method. Additionally, their relationships will be explored through Fuzzy Interpretive Structural Modelling (Fuzzy ISM). Integrating Industry 4.0 into production planning and control is expected to revolutionize the ability to adapt to evolving customer demands, enhance agility, optimize inventory management, facilitates timely decision-making, and improve control over the industrial value chain.

This thesis also emphasizes on identifying and prioritizing enablers and barriers to implementing Industry 4.0 in production planning and control. The identified enablers and barriers are then analyzed for their interrelationships and practical applications. The adoption of Industry 4.0 has witnessed significant growth, particularly in the post-pandemic era, as industries aim to enhance connectivity and efficiency in operations compared to previous practices. This research focuses on examining the catalysts and impediments critical to implementing Industry 4.0 in production planning and control within organizations.

We have stepped into an era where Industry revolution 4.0 is being accepted by each and every MSME and to a great extent it is helping huge by remarkable difference. Nowadays digital media is the forum where we are working and having inter linkage between all industries gives an extra edge to maintain their stocks, to maintain their raw materials, to upkeep their planning, to upkeep their inventories and cash flow. Industry 4.0 is not only a revolution, but it is also a culture every industry is flowing towards. This techno advancement is such a tool which is not only restricted to the manufacturing industry, but this technology is borrowed by the service industry as well. This is the era where everyone is accounted for every work. Moreover, this study reflects the mesmerizing nature of technology which is depicted by the Delphi study done by all of the tycoons in their field. As per them, Industry revolution 4.0 has the ability to run any business from anywhere across the globe irrespective of their size and shape of the business. This paper mainly focuses on the usage of IIOT (Industrial Internet of Things)

which is the hardware from which data is gathered, then usage of Cloud where data is stored and analyzed.

Industry 4.0 represents a transformative revolution that requires the digitalization of both mechanized and manual processes, enabling seamless interconnectivity through web-based technologies. This transformation ensures that human interactions with these systems are more dynamic, real-time, and informed. In any industrial setting, production planning serves as a critical function, while its effective control poses significant challenges that often exceed the capabilities of manual human intervention. In any industry controlling production is unique and most important in terms of cash flow. We need to focus on the pain points where three departments act in operation and synchronizing between them is the only activity which needs to be managed by any tool to have control over cash flow. These departments are SCM, Planning and Marketing. Now if the tool is required, there needs to be a tool which should be live and updated right from marketing to the raw material planning at the last most tier company. This reduces committing wrong and overproduction for small companies where capital flow is very limited and sailing their boat continuously will not affect the giant chunk. This study utilizes a Delphi method, following an extensive literature review, to identify the most relevant readiness factors among leading automobile manufacturers. The identified factors are analyzed for their significance using the Fuzzy COPRAS method. Additionally, enablers and barriers to implementing Industry 4.0 are determined using a Fuzzy Delphi study conducted among top decision-makers, with their importance ranked through the Fuzzy Best Worst Method. The research employs a qualitative approach, engaging key stakeholders from top Indian automakers, including senior and mid-level management as well as business consultants, to ensure diverse and unbiased results.

The study highlights areas where previous attempts have faltered and identifies critical focal points for successful implementation. Using statistical methods, the research ranks catalysts and impediments, with high-ranking enablers considered prerequisites for implementation and top-ranking barriers seen as significant hurdles that demand careful planning. The findings provide practical insights and actionable recommendations for organizations beginning their Industry 4.0 journey in production planning and control.

Furthermore, this thesis outlines opportunities for future research in production planning using advanced Industry 4.0 tools such as Artificial Intelligence, Virtual Reality, and Augmented Reality. Industry 4.0 enables technologies like Big Data Analytics and Machine Learning to integrate seamlessly with existing production processes, fostering smart manufacturing capabilities. Predictive maintenance is a key focus, enabling business owners to proactively address potential equipment failures before they impact production. The study introduces a Multi-Linear Regression (MLR)-based predictive maintenance model leveraging IoT and fog computing, providing information transparency and efficient process management through the Industrial Internet of Things (IIoT).

The proposed model optimizes maintenance prediction, reduces execution time, minimizes costs, and lowers energy consumption compared to existing methods. It forecasts rapid machinery failures effectively, supporting seamless production and servicing processes. The outcomes of this research provide significant value to industry practitioners and contribute to advancing the implementation of Industry 4.0 in production planning and control.

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Chapter 1

INTRODUCTION

Chapter Overview

This chapter provides an overview of the importance of Industry 4.0 and Production Planning and Control. This section provides details about the relevance of automobiles in manufacturing. This section will focus on the identification of the real problems faced by Production Planning and Control and what are the needs for the study where we can find some solution to overcome the problems identified. This section also covers the research methods which is to be applied for finding out the solutions to the problem identified.

1.1 Industry overview

Industries are currently operating at an unprecedented pace and efficiency, achieving milestones previously unseen. Their remarkable recovery and growth in the stock market following the downturn caused by the 2020 pandemic stand out. Many industries have surpassed their 52-week high targets within a short span of time. A key example is the Nifty 50, representing India's top Fortune 50 companies, which has demonstrated a significant upward trend in its performance post-pandemic.

Figure- 1.1 Nifty 50 Graph

Source: Singh et al. (2024)

The Nifty 50 graph shown in Figure 1.1 demonstrates the Indian market's recovery after the steep decline during the pandemic in March 2020. Following this downturn, the market surged and nearly doubled its pre-pandemic levels, showcasing the resilience of the Indian economy and its industries. This rebound occurred as Indian automobile manufacturers, among other industries, adapted to remote work by incorporating advanced technologies, which are at the core of Industry 4.0 (Chaudhary, 2021; Kumar et al., 2022). During this period, businesses in India began to explore strategies previously unconsidered, such as the ability to remain connected to manufacturing units remotely—a fundamental aspect of Industry 4.0 (Gupta & Mishra, 2021).

In many ways, the pandemic acted as a catalyst for the adoption of Industry 4.0, particularly within the Indian automobile sector, pushing industries to embrace this new digital era (Prakash et al., 2022). Production planning, a critical function with many interdependent activities, had to adapt to the volatility of today's customer-driven market. With increased competition and customer impatience, merely being agile in manufacturing is no longer sufficient for long-term success. Indian automobile manufacturers must enhance their capabilities, align with customer demands, and deliver solutions faster than competitors. Speed and efficiency have become paramount in all aspects of industrial operations (Sharma & Verma, 2020). To meet these expectations, organizations require advanced tools to achieve their objectives. Industry 4.0 in production planning and control enables Indian automobile companies to connect with stakeholders, suppliers, and production units in real time, facilitating lean operations and improved target achievement (Rai et al., 2021). One key benefit is faster decision-making, with quicker implementation of those decisions on the shop floor. Additionally, staying connected ensures that all relevant parties are continuously updated on the status of ongoing work. Sales and marketing teams can access live data to make informed commitments to customers, while suppliers and vendors benefit from real-time updates from parent organizations (Mishra et al., 2022). Furthermore, the integration of Industry 4.0 into production planning offers advantages in inventory management, allowing organizations to work with real-time inventory levels and address operational constraints that are automatically detected through smart systems. This technological transformation maximizes automation, making production planning and control more efficient and responsive (Singh & Kaur, 2023). The COVID-19 pandemic accelerated the adoption of Industry 4.0, driving Indian industries, including the automobile sector, to embrace digital transformation more rapidly (Sinha & Patel, 2023). Production planning, with its numerous interconnected activities, has become increasingly crucial in India's volatile, customer-centric market. Meeting customer expectations and responding swiftly to market demands have grown imperative, with speed and efficiency emerging as key factors for competitiveness. Industry 4.0, when integrated into production planning and control, provides advanced tools that allow Indian businesses to connect with stakeholders, suppliers, and production units in real-time. This connectivity fosters streamlined operations, improves alignment with customer demands, and enables faster, more effective decision-making on the shop floor (Joshi et al., 2022). Real-time data sharing among teams allows for informed commitments to customers, while suppliers benefit from updated information shared by the manufacturing organization. Furthermore, Industry 4.0 technologies enhance inventory management by enabling systems to automatically adjust to real-time inventory levels and operational constraints. This transformation boosts automation, making production planning and control more efficient and responsive to changing conditions (Agarwal et al., 2023).

As the industrial landscape undergoes significant changes, the fourth industrial revolution, or Industry 4.0, is transforming entire sectors, including India's automobile industry. First introduced in 2011 by Henning Kagermann, Industry 4.0 emphasizes connectivity, with digital integration between machines, employees, orders, and suppliers enabled by technologies like the Internet of Things (IoT) and the Industrial Internet of Things (IIoT) (Kagermann, 2011). The goal of Industry 4.0 is to foster smart manufacturing environments where machinery and products can interact autonomously, thus facilitating what are known as "smart factories," characterized by interconnected machines, processes, and logistics (Bansal & Gupta, 2022). Technologies like cyber-physical systems, IoT, robotics, big data, and cloud computing drive these systems, enabling real-time responses in manufacturing and supply chains (Rao et al., 2022). Industry 4.0 tools, including machine learning, artificial intelligence, and business analytics, contribute significantly to automation, helping organizations derive value from the data generated and reinforcing the need for accelerated digital adoption. Early adopters, particularly those with an innovative culture, recognize these digital tools' potential to enhance business models and have integrated them to gain a competitive edge. Digital transformation not only enhances production processes but also reshapes business models and corporate governance, thanks to continuous advances in information technology and data analytics (Chopra et al., 2023).

Consequently, many organizations are developing self-assessment models to evaluate their readiness for Industry 4.0, an essential step in navigating this transformative period. A widely recognized tool, the "IMPULS – Industrie 4.0 Readiness" model, assesses two key areas—strategy and culture, as well as smart factory capabilities (IMPULS Foundation, 2015). This model evaluates whether a company has the necessary technology and network infrastructure, along with a culture that promotes innovation. Building on the IMPULS model, this study aims to refine an assessment tool specifically for production planning and control, a critical area for aligning manufacturing operations with Industry 4.0 standards (Das et al., 2023). Industry 4.0 is essential for companies aiming to stay competitive in an era marked by technological advances, yet significant barriers remain, particularly in developing nations. In India, for example, obstacles include skill gaps, regulatory challenges, and outdated education systems, as well as limited technology access for small and medium enterprises (SMEs) (Reddy & Nair, 2022). Recognizing this, the Indian government has initiated programs like "SAMARTH Udyog Bharat 4.0" to drive Industry 4.0 adoption across sectors, with a focus on building a digital ecosystem in manufacturing (Government of India, 2021). Despite these initiatives, Industry 4.0 adoption in India is still at an early stage, with challenges including uneven adoption rates across different organization sizes and a lack of frameworks tailored to India's specific needs. Policy reforms, including GST and the "Make in India" campaign, support digital transformation, but larger companies typically advance more quickly than smaller firms, creating a fragmented landscape (Mishra & Sinha, 2023). There is a growing need for readiness models specifically designed for Indian manufacturing that can assess current capabilities, pinpoint gaps, and guide companies in their digital transformation. Developing an assessment framework tailored to the Indian context would allow manufacturers to navigate the challenges of adopting Industry 4.0 technologies, ensuring they remain competitive in the global market. This research will focus on developing an Industry 4.0 readiness framework for the Indian automobile industry, where efficient production planning and control are essential to managing complex operations in a fast-paced, customer-driven market. This study seeks to identify readiness levels, critical factors, and challenges in adopting Industry 4.0, using a comprehensive case study within the Indian manufacturing sector. The findings will provide insights into the current state of digital adoption, the primary challenges faced by the industry, and strategic recommendations for facilitating the transition to a digitally connected and data-driven environment (Raj et al., 2023).

1.2 The Manufacturing Sector and its relevance

The manufacturing sector in India has historically been a key driver of economic growth and technological innovation (Singh, 2021). In recent years, this sector has been profoundly influenced by the emergence of Industry 4.0, a transformative industrial paradigm that integrates advanced digital technologies, data analytics, and automation into Indian manufacturing processes (Kumar & Sharma, 2020). Industry 4.0 encompasses a variety of innovations, including the Internet of Things (IoT), artificial intelligence (AI), big data, and cyber-physical systems, which collectively represent a significant shift in operational practices (Chaudhary et al., 2022). The Indian automobile industry, as a cornerstone of the manufacturing sector, has particularly felt the impact of this paradigm shift.

Production planning and control (PPC) plays a vital role in ensuring that manufacturing operations run smoothly, effectively managing resources and responding to customer demands (Mehta & Gupta, 2021). Traditionally, PPC methods in Indian industries have relied on historical data and fixed processes, which can lead to inefficiencies and slow responses to market changes, including delays in supplier responsiveness (Sharma & Patel, 2021). However, the adoption of Industry 4.0 technologies allows for enhanced PPC by facilitating real-time data analysis, predictive insights, and automated decision-making processes (Das & Banerjee, 2020). These capabilities empower manufacturers to quickly adapt to fluctuations in demand, improve supply chain management, and optimize production efficiency (Mukherjee et al., 2023). For instance, real-time data integration in Indian automobile manufacturing has enabled firms to predict maintenance needs and reduce downtime, ensuring smoother operations (Ghosh et al., 2021).

Despite the promising advantages, the transition to Industry 4.0 poses several challenges for the Indian manufacturing sector. Manufacturers must contend with issues such as technology integration, workforce skills gaps, and data security risks (Raj et al., 2022). In the Indian context, these challenges are further compounded by infrastructural constraints and the limited digital literacy of workers in small and medium enterprises (SMEs) (Rao et al., 2023). Addressing these challenges requires a collaborative effort between government initiatives, such as the "Make in India" and "SAMARTH Udyog Bharat 4.0" programs, and industry stakeholders to foster a conducive environment for digital transformation (Indian Ministry of Heavy Industries, 2022). These programs aim to create a robust ecosystem for adopting Industry 4.0 technologies, ensuring that even smaller enterprises can participate in the digital revolution. Understanding the implications of these advancements for production planning and control is essential for successfully navigating this evolving landscape (Joshi & Verma, 2021). This thesis investigates the relationship between the manufacturing sector and Industry 4.0, specifically examining how these technologies are transforming production planning and control processes in the Indian automobile industry. By reviewing existing literature, analysing relevant case studies, and identifying key challenges and opportunities, this research aims to provide a thorough understanding of the relevance of Industry 4.0 within the Indian manufacturing context. For example, insights from leading automobile manufacturers such as Tata Motors and Mahindra & Mahindra can shed light on the strategies and tools employed to overcome these challenges (Bansal & Roy, 2022). Ultimately, this exploration will contribute to a broader understanding of the future of manufacturing and its essential role in fostering economic growth and innovation in a rapidly digitizing world (Reddy et al., 2023).

1.3 Relevance of Automobile Sector under Manufacturing

The automobile industry is a vital component of the global manufacturing sector, and especially the Indian automotive manufacturing sector, which holds immense potential for growth and turnaround for the nation, serving as a key contributor to economic growth, innovation, and technological development (Srinivasan & Mehta, 2021). It is one of the largest industries globally, covering a wide array of activities, including vehicle production, parts manufacturing, supply chains, and after-market services (Mukherjee et al., 2022). In India, the automobile industry significantly contributes to the GDP and is a major employer, providing millions of direct and indirect jobs, from those working in assembly plants to employees in supplier industries such as steel, rubber, glass, electronics, and software development (Kumar & Sharma, 2023). The demand for raw materials and components in vehicle manufacturing stimulates various other industries, creating a far-reaching economic impact (Raj et al., 2022).

In terms of innovation and technological advancements, the automobile sector has always been a hub of technological innovation. Breakthroughs in areas like automation, robotics, and artificial intelligence (AI) have revolutionized manufacturing processes, boosting productivity and reducing costs (Reddy & Singh, 2023). The Indian automobile industry is also leading advancements in electric vehicles (EVs), autonomous driving systems, and connected vehicle technologies (Ghosh et al., 2021). These innovations not only impact transportation but also influence industries like energy and information technology, creating broader technological growth (Chaudhary et al., 2022). For example, the government's "Faster Adoption and Manufacturing of Hybrid and Electric Vehicles" (FAME) scheme has accelerated the shift toward sustainable transportation in India, making the nation a key player in the global EV landscape (Indian Ministry of Heavy Industries, 2022). Indian Automobile manufacturing is deeply interconnected with global supply chains, making it a highly internationalized industry (Mehta & Gupta, 2021). The sector relies on a vast network of suppliers from different countries for raw materials and components. In India, the integration of domestic supply chains with global networks highlights the critical role of the automobile industry in fostering international trade and economic cooperation (Mukherjee et al., 2023). This complex web of production and trade underscores the importance of global supply chains to both developed and emerging economies (Rao et al., 2023). The future of the automobile industry is increasingly focused on electrification, automation, and digitalization (Das & Banerjee, 2020). Electric vehicles are becoming more popular as governments push for sustainable alternatives to traditional internal combustion engines (Bansal & Roy, 2022). In parallel, advancements in autonomous driving and AI-enhanced manufacturing processes are set to revolutionize both production and vehicle use (Reddy et al., 2023). Smart factories, powered by Industry 4.0 technologies, are expected to further enhance efficiency and output in automobile manufacturing, particularly in India's competitive landscape (Joshi & Verma, 2021).

The relevance of the automobile sector in manufacturing is undeniable. It not only drives economic growth and creates jobs but also serves as a platform for technological advancements and innovation (Srinivasan & Mehta, 2021). As the industry continues to embrace sustainability and new technologies, it will remain a crucial player in shaping the future of global manufacturing and economic development (Raj et al., 2022).

1.4 Problem Identification

The automobile industry encounters several challenges in production planning and control that significantly affect efficiency, costs, and delivery timelines. These challenges stem from complex global supply chains, market volatility, and evolving technological demands, all of which require careful management to ensure smooth operations. One of the major issues is **demand forecasting uncertainty**. Inaccurate forecasts can lead to overproduction, which results in excess inventory and increased storage costs, or underproduction, which leads to stockouts and dissatisfied customers (J.D. Power, 2023). Another problem involves **supply chain disruptions**. The automotive industry is highly reliant on global suppliers for critical components, and any disruption—be it geopolitical conflicts, natural disasters, or global crises like pandemics—can severely impact production schedules. For instance, the recent semiconductor shortages have caused significant delays in vehicle manufacturing (McKinsey & Company, 2021). **Managing inventory** is another critical challenge. Automobile manufacturers require a wide variety of components, making it difficult to maintain the right balance of inventory. Excess inventory ties up capital and increases holding costs, while shortages can halt production lines, leading to inefficiencies and missed sales opportunities (Automotive News, 2023). **Production line inefficiencies** can also hinder operations. Poorly optimized workflows, bottlenecks, and machine downtime can reduce productivity and increase operational costs. Implementing lean manufacturing techniques can help mitigate these issues, but many manufacturers struggle to consistently achieve efficiency (Deloitte, 2022).

Automakers often produce multiple models on the same production line, leading to challenges in handling production complexity. Managing the production schedules for multiple vehicle models and their variants requires precise coordination. Mismanagement of these schedules can result in resource misallocation and production delays (KPMG, 2023). Finally, coordination between multiple production plants presents a significant challenge. Global automakers often operate multiple facilities across different regions, making it difficult to synchronize production schedules and resource allocation. A lack of coordination can result in inefficiencies and production delays.

1.5 Research Gap

Although Industry 4.0 technologies have advanced significantly, gaps remain in both the literature and practical applications, especially regarding their implementation in production planning and control within developing economies such as India. A research gap refers to the areas of knowledge that have not yet been adequately explored or addressed, and several gaps stand out in this field:

- **Limited Studies on Industry 4.0 in Indian Manufacturing-**While global research on Industry 4.0 is growing, the specific context of Indian manufacturing, particularly in the automotive industry, has not been adequately covered. The challenges unique to Indian industries—such as infrastructure limitations, workforce skills, and cost constraints—are often not explored in depth (Kamble et al., 2018). More studies are needed to develop strategies tailored to these local challenges.

- **Lack of Focus on Small and Medium Enterprises (SMEs)-** Existing research on Industry 4.0 tends to concentrate on large enterprises with substantial financial and technological resources. However, SMEs, which are a critical component of the Indian economy, face unique challenges in adopting these technologies. There is limited research that addresses the financial, technical, and operational barriers that prevent SMEs from fully benefiting from Industry 4.0 (Mittal et al., 2018). It is often recorded that the whole production line suffers due to the unavailability of any C class components which are supplied by some small and medium enterprise.
- **Workforce Readiness and Skill Gaps** A critical element for Industry 4.0 implementation is workforce readiness, particularly the skills required to work with new technologies. However, comprehensive research on the current skill levels of the Indian workforce, as well as effective strategies for training and upskilling, is lacking (Chaudhary et al., 2021). There is a need for more detailed studies on how the labor force can be prepared for the technological demands of Industry 4.0.
- **Integration of Legacy Systems-** Many Indian manufacturers continue to rely on outdated legacy systems, and there is limited research on how these systems can be effectively integrated with Industry 4.0 technologies without causing disruptions to production. The challenge of connecting old systems with new digital solutions like IoT and AI has not been sufficiently explored (Raj et al., 2020).
- **Real-Time Data Utilization-** While Industry 4.0 emphasizes real-time data for improving production processes, research on how Indian manufacturers can efficiently harness and utilize this data is scarce. More studies are required to understand the challenges related to data collection, processing, and decision-making in Indian manufacturing settings (Bag et al., 2021).
- **Cost-Benefit Analysis of Industry 4.0 Implementation-** Although the potential benefits of Industry 4.0 are frequently discussed, comprehensive cost-benefit analyses, particularly in the Indian context, are under-researched. More detailed studies are needed to quantify both the costs of implementing these

technologies and the expected long-term financial and operational benefits (Luthra & Mangla, 2018).

- **Cybersecurity and Data Privacy-** The adoption of Industry 4.0 brings with it concerns about data security and privacy, especially as companies become more connected. While these issues are explored in global literature, there is a gap in research focused on how Indian manufacturers can manage cybersecurity risks, given the unique challenges in this region (Wang et al., 2019).

In conclusion, the identified research gaps highlight the need for more in-depth, region-specific studies on Industry 4.0 implementation in production planning and control in India. These gaps underscore the importance of focusing on SMEs, workforce training, integration of legacy systems, real-time data use, and cybersecurity. Further research is essential to understand the financial, operational, and environmental implications of Industry 4.0 adoption, as well as to provide empirical evidence from Indian industries to support future strategies.

1.6 Need for the Study

Integrating Industry 4.0 into production planning and control in the Indian automobile sector has become essential for overcoming current challenges and enhancing global competitiveness. With the automotive industry facing issues like fluctuating demand, intricate supply chains, to improve operational efficiency, advanced technologies like automation, artificial intelligence (AI), the Internet of Things (IoT), and big data analytics offer vital solutions. Industry 4.0 enables optimized production planning, improved workflows, and **real-time decision-making**, which are essential for managing modern manufacturing complexities (Kamble et al., 2018). For India, where the automotive sector plays a significant role in the economy, adopting smart manufacturing technologies can help resolve issues like labour shortages, inventory mismanagement, and inefficiencies in production. Additionally, this aligns with national initiatives like "Make in India" and digital transformation efforts, driving the industry towards greater productivity, sustainability, and quality improvement (Gandhi, Magar, & Roberts, 2014). Therefore, studying the implementation of Industry 4.0 in Indian automobile production is necessary to assess its potential, challenges, and strategies for successful adoption. Since the highest potential stands with the "Real time data utilization" for implementing this Industry 4.0 in PPC, this thesis will emphasise on the aspects of real time data transfer so that the decisions could be made in real time saving inventory, transit losses and operational cost and time.

1.7 Research Questions

- What are the critical readiness factors for implementing Industry 4.0 in production planning and control within the Indian automobile industry?
- What are the key enablers and barriers influencing the successful adoption of Industry 4.0 in PPC in the Indian context?
- How can the Indian automobile industry prioritize and address these enablers and barriers to optimize Industry 4.0 implementation in PPC?
- What contextual relationships exist among the identified enablers and barriers, and how do they interact to impact PPC processes?

1.8 Research Objectives

Based on the gaps identified and the research questions, the specific objectives of this study are as follows:

- ***To identify and analyze the readiness factors of the industries for the implementation of Industry 4.0 in Production Planning and Control.*** This objective aims to assess the preparedness of the Indian automobile industry for adopting Industry 4.0 technologies in its PPC processes. Readiness factors such as infrastructure, technological capabilities, organizational culture, and workforce skills will be analyzed.
- ***To identify the critical catalysts and impediments for the implementation of Industry 4.0 in Production Planning and Control of automobile industries.*** The study seeks to determine the key drivers (catalysts) that facilitate the adoption of Industry 4.0 technologies, as well as the major barriers (impediments) that hinder their successful implementation. These may include technological advancements, market demand, financial investment, and employee resistance.
- ***To prioritize the list of critical catalysts and impediments identified for the implementation of Industry 4.0 in Production Planning and Control of***

automobile industries. This objective will prioritize the catalysts and barriers in terms of their significance and impact on the adoption of Industry 4.0 in PPC. This prioritization will help industry leaders focus on addressing the most important factors first.

- ***To analyze the contextual relationships among the identified catalysts and impediments.*** Understanding how the various catalysts and impediments interact with one another is crucial for developing a successful strategy for implementing Industry 4.0. This objective aims to explore these relationships, providing insights into how to create a balanced and effective roadmap for PPC transformation.

1.9 Scope of the study

The scope of this study encompasses the examination of Industry 4.0 technologies and their impact on production planning and control within the Indian automotive sector. Specifically, it will explore how the integration of technologies such as the **Internet of Things (IoT),** big data analytics, artificial intelligence (AI), and automation can enhance efficiency, reduce operational costs, and improve decision-making in real-time. This study aims to assess the current level of Industry 4.0 adoption in India, identify key barriers to its implementation, and evaluate the potential benefits for production processes. Additionally, the research will cover strategies to overcome challenges related to technology integration, workforce training, and infrastructure development. By focusing on the Indian automotive industry, this study seeks to provide insights into how these advancements can contribute to the country's broader manufacturing growth and align with national initiatives like "Make in India" (Kamble et al., 2018). This study will also make a glide path and step by step procedure for any small, medium or large automobile industry to follow for implementing Industry 4.0 in PPC. This thesis includes the data collected from various automobile companies with their top officials working.

1.10 Proposed Methodology

Table- 1.1 Research Objectives and Methodology adopted

S. No.	***Research Objectives***	***Tool Used/ Methodology adopted***
A.	To identify and analyze the readiness factor of the automobile industries for implementation of Industry 4.0 in Production Planning and Control	***Systematic Literature review/ Fuzzy Delphi study & Fuzzy COPRAS***
B.	To find out the critical catalysts and impediments for implementation of Industry 4.0 in Production Planning and Control of automobile industries	***Systematic Literature review/ Fuzzy Delphi study***
C.	To prioritize the list of critical catalysts and impediments identified for implementation of Industry 4.0 in Production Planning and Control of automobile industries	***MCDM (Fuzzy BWM)***
D.	To analyze the contextual relationship among the identified catalysts and among the identified impediments	***Fuzzy ISM (Interpretive Structural Modelling)***

1.11 Expected outcome of the proposed study

The expected outcome of the proposed study is to provide a comprehensive understanding of how Industry 4.0 technologies can enhance production planning and control within the Indian automotive industry. By analysing the integration of technologies like artificial intelligence, big data, automation, and the Internet of Things (IoT), the study aims to identify improvements in operational efficiency, resource management, and decision-making processes. The findings are anticipated to highlight reductions in production downtime, optimization of supply chain management, and more accurate demand forecasting. Additionally, the research is expected to offer insights into overcoming the challenges of implementation, such as the need for workforce upskilling and infrastructure development. Ultimately, the study will contribute to the broader body of knowledge on digital transformation in manufacturing and support Indian automotive manufacturers in achieving higher productivity and sustainability (Kamble et al., 2018).

Table1.2 Proposed Research outcomes

S.NO	Research Gaps	Research Questions	Research Objectives	Research Outcome
A	To successfully adopt Industry 4.0 in production planning and control, industries need to be equipped with the latest technologies, effective management practices, and a skilled workforce. However, academic research on the factors influencing Industry 4.0 implementation and their detailed analysis is limited.	What are the key factors determining the readiness of industries for implementing Industry 4.0 in production planning and control?	To identify and analyse the readiness factors for implementing Industry 4.0 in production planning and control.	Industries can evaluate their readiness for adopting Industry 4.0 in production planning and control by analysing these factors.
B	Although catalysts and impediments for Industry 4.0 have been identified in areas like supply chain management, logistics, and plant operations, there is a lack of research on the specific	What are the catalysts and impediments for implementing Industry 4.0 in production planning and control?	To identify the critical catalysts and impediments for implementing Industry 4.0 in production	To identify the importance of each catalyst and impediment among those identified.

	catalysts and impediments for its implementation in production planning and control.		planning and control.	
C	Understanding the key driving and obstructing factors is crucial for industries planning to implement Industry 4.0. However, research on identifying and prioritizing these enablers and barriers in production planning and control is scarce.	What are the main enablers and barriers to focus on for implementing Industry 4.0 in production planning and control?	To prioritize the list of critical catalysts and impediments for implementing Industry 4.0 in production planning and control.	A prioritized list of critical catalysts and impediments will identify which factors are most and least relevant.
D	Analysing the relationship between key enablers and barriers for implementing Industry 4.0 in production planning and control is essential for industries, but academic literature on this relationship is lacking.	How can the relationship between key enablers and barriers for implementing production planning and control be analysed?	To analyse the contextual relationships among the identified catalysts and impediments.	Industries will be able to develop a mitigation plan based on the relationships between identified catalysts and impediments.

1.12 Chapterization

This thesis is organised and structured into five chapters. Chapter one deals with the introduction part of the Industry 4.0 and Production Planning and Control. It also emphasizes the importance of integration of Industry 4.0 and Production planning and control giving the importance of automobile sector in India. Further, this chapter describes about the research gap, research questions and their objectives, scope and proposed methodology of the study. Chapter two consist of extensive literature review blend with bibliometric analysis related to the theme of Industry 4.0. Chapter three represents the research methodologies adopted under the study that includes qualitative and quantitative research techniques as well, utilizing advanced tools such as Fuzzy Delphi, Multi-Criteria Decision-Making (MCDM), and Fuzzy Interpretive Structural Modelling (Fuzzy ISM) to ensure a comprehensive and reliable analysis. Chapter four highlights the results obtained of the research work based on various methodologies adopted where all the research questions have been answered, and all the objectives have been covered. This chapter also demonstrates the effectiveness and result validation of incorporating Industry 4.0 in production planning and control. Chapter five comprises the summary and conclusion for the research work where strength and uniqueness are elaborated with suggestions and limitations. This chapter also incorporates future research directions and implications.

Chapter 2

LITERATURE REVIEW

Chapter Overview

This chapter includes the review of the existing literatures collected from primary and secondary sources. It includes bibliometric analysis of the data collected followed by detailed extensive literature review. This chapter also digs down the short comings of the research done in past and showcases how this research will help in closing the shortcomings.

2.1.Basis for the Literature Survey

The literature survey on the implementation of Industry 4.0 in production planning and control was structured around key foundational elements, incorporating both Systematic Literature Review (SLR) and Extensive Literature Review (ELR), along with bibliometric analysis. The primary objective of the review was to explore existing research on the application of Industry 4.0 technologies—such as the Internet of Things (IoT), big data analytics, artificial intelligence (AI), and cyber-physical systems—in optimizing production planning and control processes. This included examining how these technologies enhance manufacturing processes, increase operational efficiency, and contribute to smarter decision-making.

The scope of the review encompassed a wide range of academic articles, case studies, and industry reports published primarily within the past decade, ensuring the inclusion of the latest advancements and trends in Industry 4.0. While the literature reviewed was global in scope, particular emphasis was placed on industries that have been early adopters of Industry 4.0 technologies, such as the automotive, aerospace, and electronics manufacturing sectors (Müller et al., 2021).

Inclusion Criteria:

1. **Relevance to Industry 4.0 and PPC:** Studies must focus on Industry 4.0 technologies and their application in production planning and control.

2. **Peer-Reviewed Sources:** Only peer-reviewed journal articles, conference proceedings, and high-quality industry reports are considered.
3. **Publication Date:** Articles published in the last 10–15 years to ensure the inclusion of recent advancements.
4. **Empirical and Theoretical Studies:** Both empirical case studies and theoretical research on Industry 4.0 implementation in PPC are included.
5. **Geographical Scope:** Studies covering global trends as well as research specifically relevant to the Indian automobile industry.
6. **Language:** Only studies published in English are considered.

Exclusion Criteria:

1. **Irrelevant Topics:** Studies focusing on general Industry 4.0 applications without specific relevance to PPC.
2. **Low-Quality or Non-Peer-Reviewed Studies:** Articles from non-peer-reviewed sources, blogs, and opinion pieces.
3. **Outdated Literature:** Studies published before 2010 unless they provide foundational theories.
4. **Duplicate Studies:** Redundant studies or those with overlapping findings from the same authors.
5. **Non-English Publications:** Studies published in languages other than English due to accessibility constraints.

Criteria for Selection

Sources were chosen based on their relevance to the core themes of Industry 4.0, particularly in the context of production optimization, predictive maintenance, and intelligent decision-making. Priority was given to peer-reviewed journals, conference papers, and highly cited industry reports to ensure academic rigor. Reports from leading manufacturing organizations like Siemens and Bosch, who have implemented Industry 4.0 technologies, were also considered (Siemens AG, 2020; Bosch Group, 2019).

Theoretical Framework

The literature was examined within the industry 4.0 theoretical framework, primarily developed in Germany's high-tech strategy (Kagermann et al., 2013). This framework outlines the integration of digital technologies to create smart, interconnected manufacturing environments. The review also considered theories related to cyber-physical systems (CPS) and digital twins in production environments (Tao et al., 2018).

The literature survey adopted a positivist approach, emphasizing empirical evidence from case studies and quantitative data in production planning and control systems. This was combined with interpretivism, where qualitative insights from industry reports were used to assess the practical challenges of Industry 4.0 implementation.

Bueno (2020) answers to the question about the smart capabilities necessary for PPC through exploration of smart technologies, networking power and smart manufacturing planning and control. The same study definition of smart capabilities is carried from Arbix et al. (2017) as resources and capabilities that support PPC function towards integration, automation and digitalization. Bueno (2020) also provided the performance implication if PPC is integrated with industry 4.0.

Pozzi et al. (2023) developed a conceptual model identifying contextual factors from a literature review as critical to the implementation of Industry 4.0. They emphasized that adopting Kaizen practices plays a vital role in ensuring the successful integration of Industry 4.0 technologies. The outcomes of this implementation, whether incremental or revolutionary, have a significant impact on production planning and control (PPC). Reyes et al. (2023) highlighted the importance of logistics chain relationships in their study, focusing on key performance indicators such as delivery lead times, inventory levels, supply costs, service quality, and customer satisfaction. Their research included interviews with experts from the footwear manufacturing sector and a survey conducted with senior executives from shoe manufacturing companies, using questionnaires designed in collaboration with industry specialists.

2.2.Philosophy of the Literature Review

This review is basically divided into two parts, Bibliometric analysis and Extensive Literature Review. This review is structured to reflect critical, integrative, comparative, methodological, and pragmatic perspectives. The concept of Industry 4.0 represents a paradigm shift in manufacturing, marked by the integration of digital technologies into production processes. This literature review examines the implications of Industry 4.0 on production planning and control, emphasizing the need for critical analysis and synthesis of existing research. By utilizing various philosophical approaches, this review aims to uncover insights that inform future research and practical applications in the field. Industry 4.0 is characterized by the convergence of cyber-physical systems, IoT, artificial intelligence (AI), and big data analytics. These technologies enhance operational efficiency, flexibility, and responsiveness in manufacturing (Kagermann et al., 2013). As organizations adopt these innovations, understanding their impact on production planning and control becomes essential.

A critical examination of the literature reveals several strengths and weaknesses in the research surrounding Industry 4.0. While many studies emphasize the potential benefits, such as improved efficiency and reduced lead times (Mourtzis et al., 2016), others highlight significant challenges, including workforce readiness, integration issues, and cybersecurity threats (Bouras et al., 2020; Kamble et al., 2020). Workforce Skills Gap: The transition to Industry 4.0 necessitates a workforce skilled in digital technologies. Bauernhansl et al. (2014) argue that the lack of training and education in these areas poses a significant barrier to implementation. Integration Challenges: Many organizations struggle to integrate new technologies with existing systems. Tao et al. (2018) highlight compatibility concerns that can lead to increased operational complexity and costs. Cybersecurity Concerns: As connectivity increases, so do the risks of data breaches. Bouras et al. (2020) emphasize the need for robust security frameworks to safeguard sensitive information.

An integrative approach allows for a comprehensive understanding of how various technologies associated with Industry 4.0 contribute to production planning and control. The combination of IoT and AI enhances real-time data access, enabling timely decision-making and adjustments (Li et al., 2018). Predictive analytics improves forecasting accuracy, optimizing inventory management (Kumar & Singh, 2021).

Furthermore, integrating findings across disciplines highlights the interconnectedness of production planning, supply chain management, and information technology. For instance, studies by Xu et al. (2018) emphasize how cloud computing facilitates collaboration across departments, enhancing organizational flexibility and responsiveness. Comparing case studies from different organizations provides insights into diverse approaches to implementing Industry 4.0 technologies. For example:

Siemens: Siemens has effectively utilized IoT and AI to streamline its production lines, resulting in significant efficiency gains (Siemens AG, 2020).

General Electric (GE): GE's use of predictive analytics has led to optimized maintenance schedules and reduced equipment failures, showcasing the impact of data-driven decision-making (GE Digital, 2021).

Bosch: Bosch's integration of smart sensors has improved visibility and control in production, allowing for real-time adjustments based on demand fluctuations (Bosch Group, 2019).

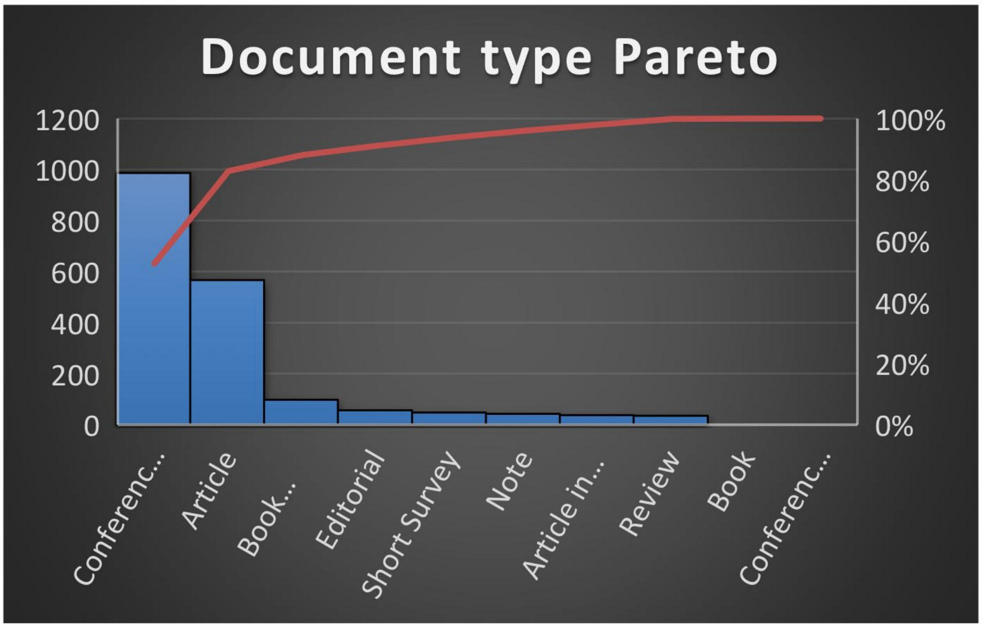
These case studies illustrate the varying outcomes and best practices across industries, underscoring the importance of context in implementation strategies. A methodological perspective reveals the diverse research designs employed in studying Industry 4.0. Quantitative studies often focus on performance metrics and statistical analyses (Müller et al., 2021), while qualitative research explores organizational culture and change management (Chiarini, 2021). Understanding these methodologies is crucial for guiding future research and ensuring robust study designs.

Mixed-Methods Approaches: Some studies successfully combine qualitative and quantitative methods to provide a more holistic view of the challenges and opportunities associated with Industry 4.0 (Wang et al., 2016). A pragmatic approach emphasizes the practical implications of research findings. The literature suggests that organizations can achieve significant operational improvements by adopting Industry 4.0 technologies, but success hinges on addressing implementation challenges (Kamble et al., 2020). Future research should focus on developing frameworks that guide organizations in navigating the complexities of Industry 4.0 adoption. For example, integrating sustainability initiatives into Industry 4.0 strategies can drive both efficiency and environmental responsibility (Müller et al., 2021). The implementation of Industry 4.0 technologies presents a complex interplay of opportunities and challenges for production planning and control. Through critical analysis, integrative synthesis, comparative perspectives, methodological insights, and pragmatic applications, this literature review highlights the multifaceted nature of Industry 4.0. Addressing existing gaps and challenges is essential for organizations aiming to harness the full potential of these technologies.

2.3.Bibliometric Analysis

Bibliometric analysis is a quantitative research methodology used to assess the structure, development, and trends in a specific field of study. This analysis involves systematic collection and evaluation of academic publications, citations, keywords, and authors, providing insights into the growth, impact, and evolving themes within the research community. In the context of Industry 4.0 and its implications for production planning and control (PPC), bibliometric analysis helps us understand how research has evolved over time, the most influential papers, and the direction of technological advancements in manufacturing. This analysis uses data from academic databases like Scopus and Web of Science and covers publications from 2010 to 2024. The key search terms for gathering relevant data included **"Industry 4.0," "production planning," "control,"** and **"smart manufacturing."**

Figure2.1 Document Type Pareto



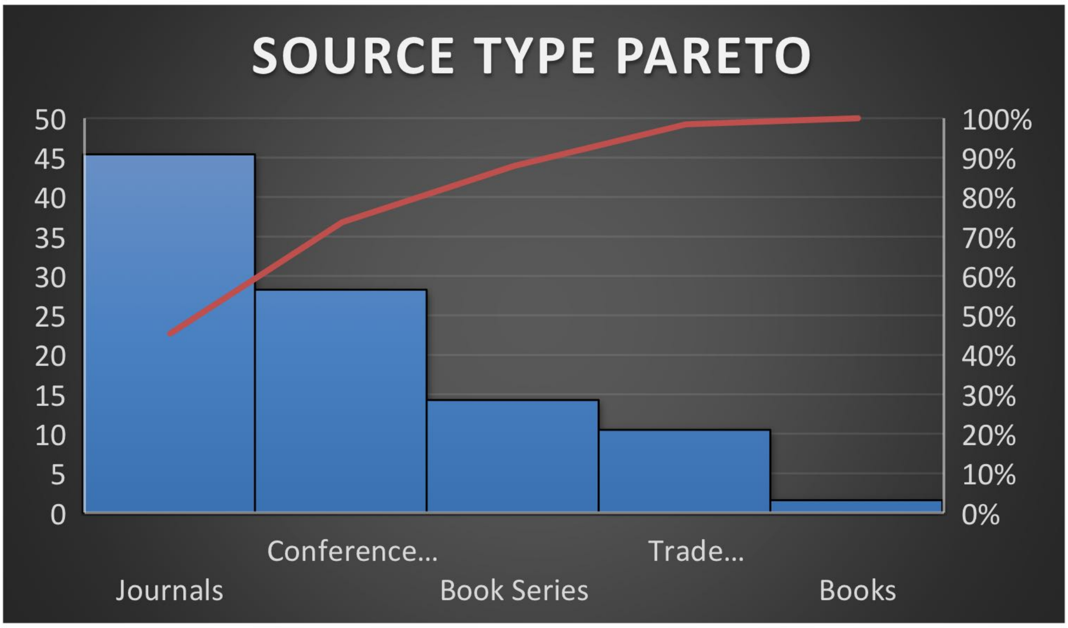
Source: author’s own work

Table 2.1- Frequency and Pareto for Document Type

Document type	Frequency	%
Conference Paper	987	53%
Article	567	30%
Book Chapter	98	5%
Editorial	57	3%
Short Survey	48	3%
Note	43	2%
Article in Press	38	2%
Review	35	2%
Book	2	0%
Conference review	1	0%
Total	**1876**	**100**

Source: author's own work

Figure2.2 Pareto for Type of Source

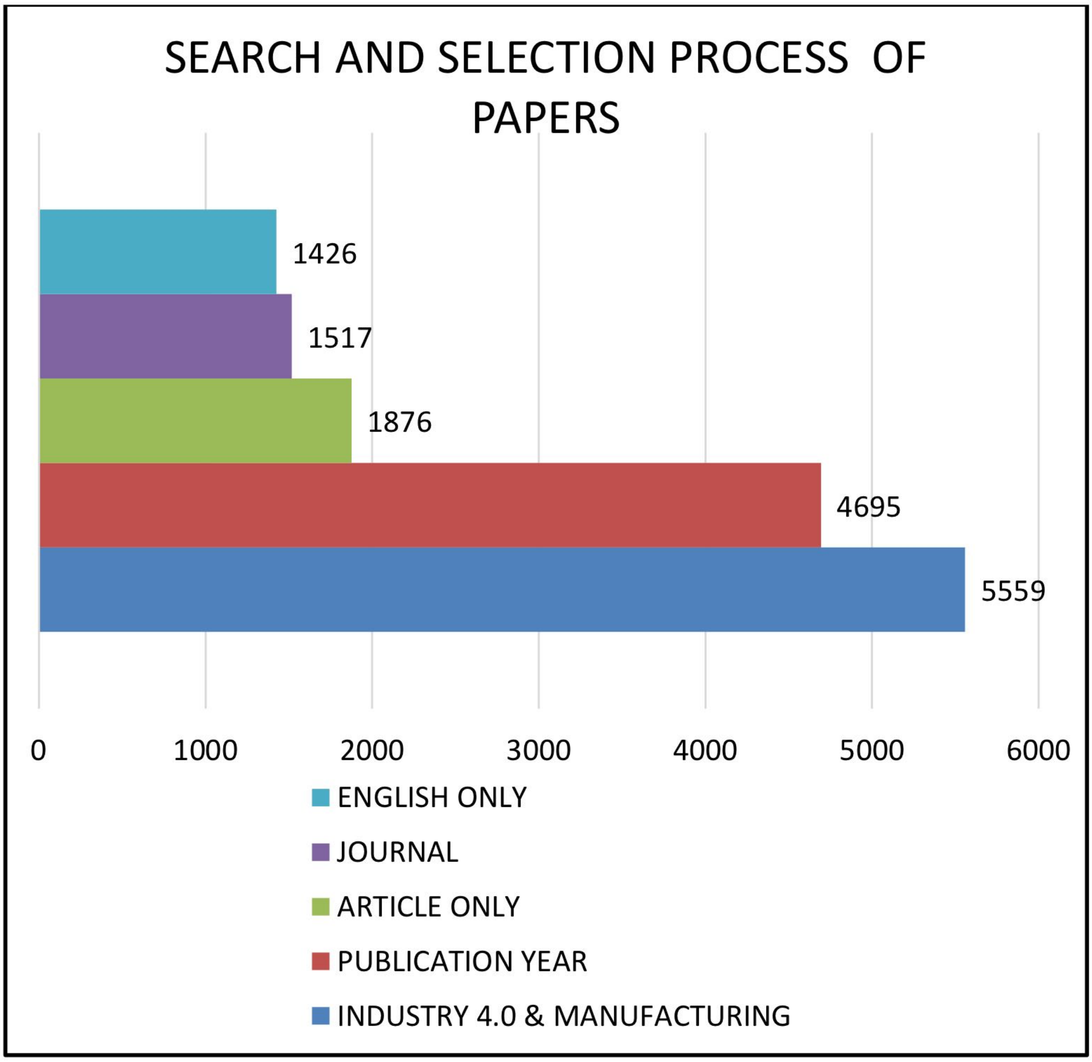


Source: author's own work

Table-2.2 Pareto for Type of Source

Source Type	**Frequency**	**%**
Journals	852	45.39
Conference Proceedings	530	28.25
Book Series	268	14.26
Trade Publications	225	11.51
Books	2	0.59
Total	**1876**	**100**

Figure 2.3   Search and selection process of papers



Source: author's own work

The search was carried out on June 18, 2021. The total number of extracted documents was 5559, which was reduced to 4695 after confining the articles to the last five years, i.e. 2016–2020.

Publication Trends

2010-2015: Early Years of Research

The first half of the decade (2010-2015) saw limited research output on Industry 4.0, particularly related to production planning and control. With fewer than 50 publications per year, this period was primarily focused on the foundational conceptualizations of

smart manufacturing and digital transformation within industries. These initial works focused on early technological developments, such as cyber-physical systems (CPS) and the advent of the **Industrial Internet of Things (IIoT)**.

Key observations:

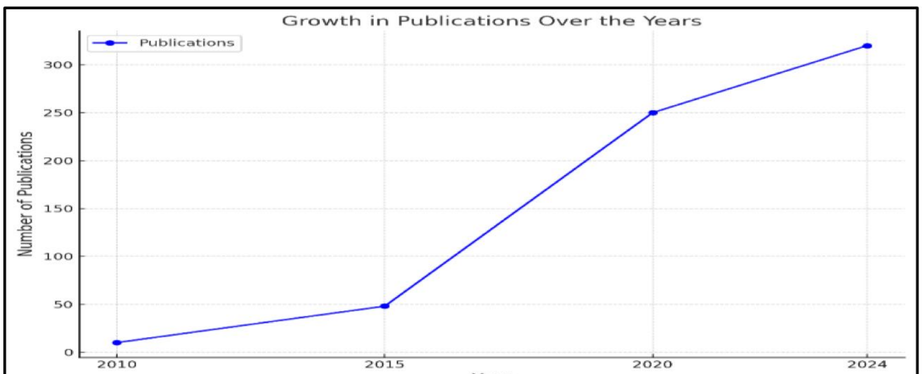
- Research publications were limited, with fewer than 50 papers per year.
- Focused mainly on conceptualizing Industry 4.0 technologies.
- Some early-stage studies on digitalization and automation in manufacturing.

2016-2024: Rapid Growth in Research Output

From 2016 onwards, the number of publications surged significantly, reaching over 200 publications per year by 2019, reflecting the growing investment in Industry 4.0 technologies. This uptick in research output is attributed to increased academic interest in digital transformation, automation, and the integration of advanced technologies like **AI, Big Data, Robotics,** and **IoT** into manufacturing.

By 2024, preliminary estimates suggest that the number of publications will exceed **320** per year, driven by further technological advancements and increased adoption of Industry 4.0 technologies in manufacturing processes. Additionally, the COVID-19 pandemic accelerated the adoption of digital solutions, boosting research in areas such as **remote manufacturing** and **real-time data sharing.**

Figure 2.4 Annual publication trends in Industry 4.0 research



Source: author's own work

Table- 2.3 Aannual Publication Trends in Industry 4.0 Research

Year	Publications
2010	10
2015	48
2020	250
2024	320 (est.)

Source: author's own work

The data shows a clear upward trajectory in publications, with Industry 4.0 emerging as a central theme in manufacturing and production research. This growth is attributed to both technological advancements and industry-wide investments in digitization.

Citation Analysis

Citation analysis helps identify the most influential papers in the field of Industry 4.0. The following papers are among the top-cited works, establishing the foundational theories and frameworks in the industry 4.0 landscape.

Key Citations and Influential Papers:

- **Kagermann, H., Wahlster, W., & Helbig, J. (2013).** "Recommendations for implementing the strategic initiative INDUSTRIE 4.0." This seminal paper has received over **1,500 citations** and is considered the foundational document for Industry 4.0, outlining the vision, strategies, and policies needed for successful implementation.
- **Mourtzis, D., et al. (2016).** "A survey on the Smart Factory: A review of literature and a roadmap for the future." With over **800 citations**, this paper provides a comprehensive review of **Smart Factory** concepts and serves as a roadmap for the future of digital manufacturing.

- **Bauernhansl, T., et al. (2014).** "Industry 4.0: A new industrial revolution – How Europe will succeed." Cited over **600 times**, this paper discusses how Europe can leverage Industry 4.0 technologies to maintain global manufacturing leadership.

Table 2.4 Highly Cited Papers in Industry 4.0 Research

Authors	Title	Year	Citations
Kagermann, H., et al.	Recommendations for implementing the strategic initiative INDUSTRIE 4.0	2013	1,500+
Mourtzis, D., et al.	A survey on the Smart Factory: A review of the literature and a roadmap for the future	2016	800+
Bauernhansl, T., et al.	Industry 4.0: A new industrial revolution – How Europe will succeed	2014	600+

These papers have significantly shaped the research landscape, driving forward key discussions on **cyber-physical systems (CPS), IoT, automation**, and the **Smart Factory**.

Keyword Co-Occurrence Analysis

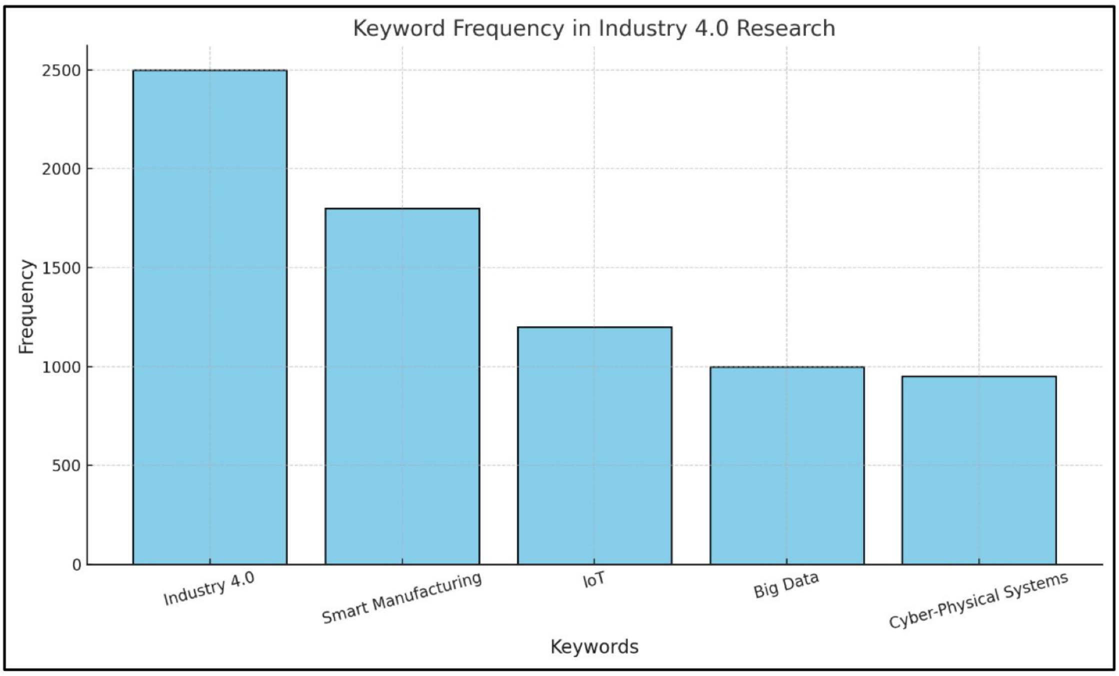
Keyword co-occurrence analysis identifies the most frequently occurring terms in the field, helping us understand the primary research themes. By analyzing the frequency of terms used in titles, abstracts, and keywords, we can identify key technologies and concepts driving the research agenda in Industry 4.0.

The most frequent keywords include **Industry 4.0**, **Smart Manufacturing**, **IoT**, **Big Data**, and **Cyber-Physical Systems**.

Key Insights:

- **Industry 4.0** is the dominant keyword in the field, occurring in over **2,500 publications**.
- **Smart Manufacturing** and **IoT** also appear frequently, indicating a strong connection between **Industry 4.0** and the evolution of intelligent, connected production systems.
- Keywords like **Big Data** and **Cyber-Physical Systems** show how advanced analytics and physical systems integration are central to Industry 4.0.

Figure 2.5 Keyword Co-Occurrence Network



Source: author's own work

Table 2.5: Co-Occurrence Network Analysis

Keyword	Frequency
Industry 4.0	2,500+
Smart Manufacturing	1,800+
IoT	1,200+
Big Data	1,000+
Cyber-Physical Systems	950+

This analysis shows how **IoT** and **Smart Manufacturing** are central to the development of Industry 4.0, highlighting their interrelationships in modern manufacturing environments.

Prominent Authors and Journals

A review of author contributions in Industry 4.0 research reveals the leading experts in the field, with significant contributions to key papers and frameworks.

Prominent Authors:

1. **Hermann Kagermann:** Widely regarded as the father of Industry 4.0, Kagermann's work has had a profound influence on shaping the vision and strategies for the digital transformation of manufacturing.
2. **D. Mourtzis:** Known for contributions to manufacturing systems and Smart Factory technologies, Mourtzis has authored several key papers and reviews on these topics.
3. **F. Tao:** A prominent figure in **Cyber-Physical Systems (CPS)**, Tao's research focuses on integrating advanced technologies with manufacturing systems.

Top Journals:

The following journals consistently publish high-impact research on Industry 4.0, production planning, and control:

Table 2.6 Impact factor of the Top Journals

Journal	Impact Factor	Focus
Journal of Manufacturing Systems	4.0+	Advanced manufacturing techniques
International Journal of Production Research	3.8+	Production planning and control
Robotics and Computer-Integrated Manufacturing	3.5+	Robotics and automation in manufacturing

Bibliometric analysis reveals a growing body of literature surrounding the implementation of Industry 4.0 in production planning and control. Research trends show a clear increase in scholarly activity, particularly from 2016 onward, driven by advancements in digital technologies and the global push towards digital transformation.

However, there are gaps in the literature, such as:

- **SMEs' adoption challenges**: Limited research on the application of Industry 4.0 in small and medium-sized enterprises, especially in emerging markets like India.
- **Workforce challenges**: The need for workforce upskilling and reskilling to match technological advancements.

- **Contextual adoption frameworks**: There is a lack of region-specific frameworks, particularly for countries like India, which faces unique challenges in terms of infrastructure, technology access, and skill gaps.

This bibliometric analysis offers a comprehensive overview of the research landscape surrounding **Industry 4.0** in **production planning and control**. The growing body of literature highlights key technological advances, challenges, and the importance of real-world applications. Future research should focus on bridging the gap between theory and practice, addressing challenges related to **implementation**, **scalability**, and **workforce readiness**.

2.4.Extensive and Systematic Literature Review

The number of publications related to Industry 4.0 has been rising exponentially, signifying its increasing penetration across industries. Industry 4.0 represents a transformative shift in manufacturing, characterized by the integration of advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data analytics, and cyber-physical systems. This literature review explores the implications of Industry 4.0 on production planning and control, focusing on optimizing processes, enhancing decision-making, and improving overall operational efficiency through a combination of an extensive literature review (ELR) and a systematic literature review (SLR).

2.4.1 Theoretical Framework of Industry 4.0

The term "Industry 4.0" was first introduced in Germany as part of a high-tech strategy to promote the digitalization of manufacturing (Kagermann et al., 2013). It emphasizes the creation of smart factories where machines, systems, and humans communicate and cooperate in real-time. The underlying technologies include IoT, cloud computing, AI, and advanced robotics, contributing to increased automation, flexibility, and efficiency in production environments (Mourtzis, 2016).

2.4.2 Technological Components of Industry 4.0

Internet of Things (IoT)

IoT is a foundational component of Industry 4.0, enabling seamless data exchange between devices and machines. This connectivity allows real-time monitoring of production processes, facilitating timely decision-making and operational adjustments (Li et al., 2018). Smart sensors track equipment performance, alerting managers to potential issues before they escalate (Wang, Wang, & Li, 2016).

Big Data and Analytics

Big data analytics in production planning helps process large datasets generated by IoT devices. Predictive analytics improve forecasting accuracy, optimize inventory levels, and enhance scheduling efficiency (Kumar & Singh, 2021). Studies indicate that organizations leveraging big data analytics achieve significant efficiency gains (Müller, Buliga, & Voigt, 2021).

Cyber-Physical Systems (CPS)

CPS integrates physical processes with computational resources, creating interconnected and intelligent production environments. Digital twins—virtual replicas of physical systems—facilitate simulations to predict and optimize performance (Tao, Zhang, Liu, & Nee, 2018). This capability is crucial for production planning as it allows organizations to test scenarios and make informed decisions based on simulations.

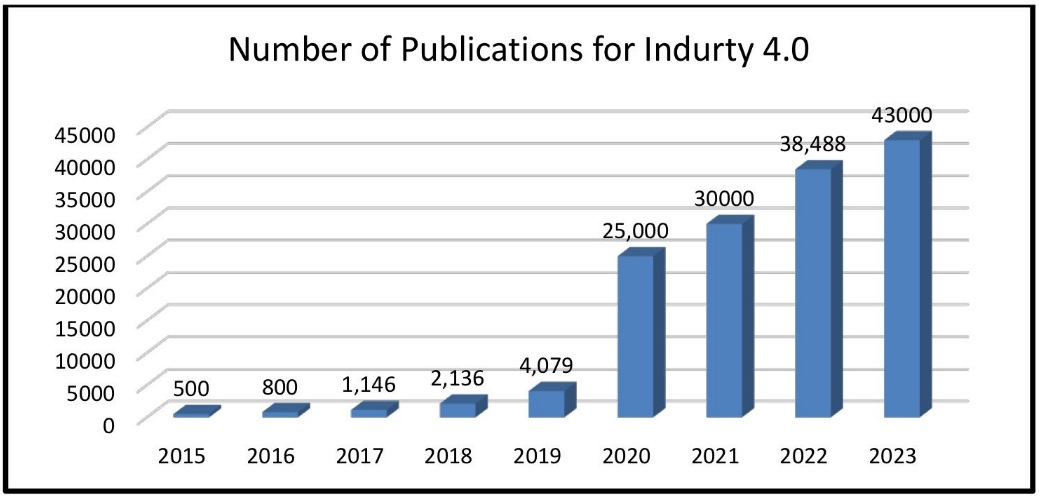
2.4.3 Impact of Industry 4.0 on Production Planning and Control

Enhanced Decision-Making

Industry 4.0 technologies significantly improve decision-making in production planning. Real-time data access enables managers to respond to current conditions rather than relying solely on historical data (Zhou, Liu, & Zhou, 2015). Adaptive production systems dynamically adjust schedules based on demand fluctuations and machine availability (Tortorella et al., 2018).

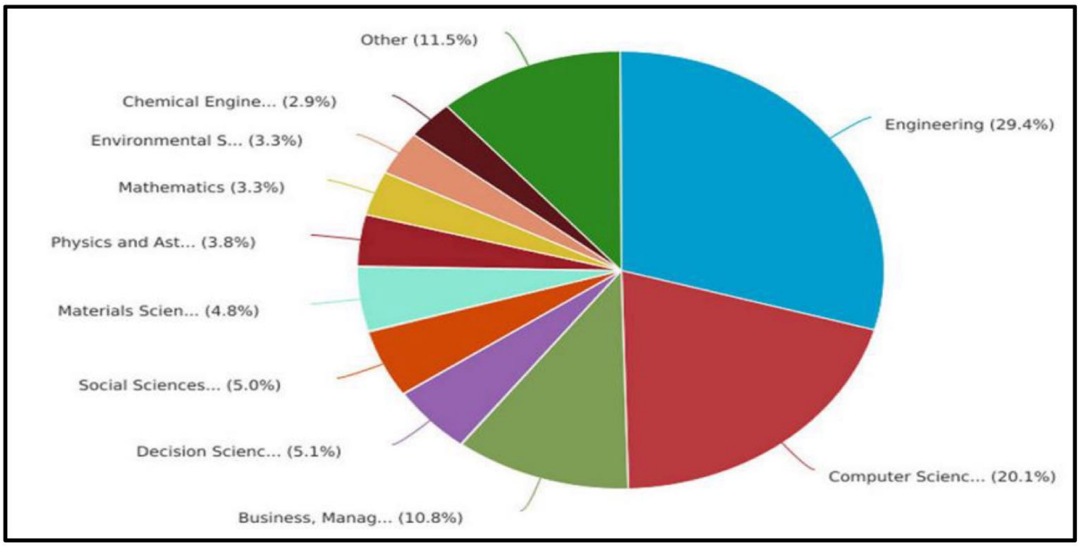
The implementation of Industry 4.0 technologies in production planning and control offers significant opportunities for enhancing efficiency, flexibility, and decision-making. However, challenges such as workforce skills gaps, integration issues, and cybersecurity risks must be addressed for successful adoption. This literature review underscores the need for continued research to explore innovative solutions and best practices in leveraging Industry 4.0 for manufacturing excellence.

Figure-2.6 Number of Publications per year for Industry 4.0



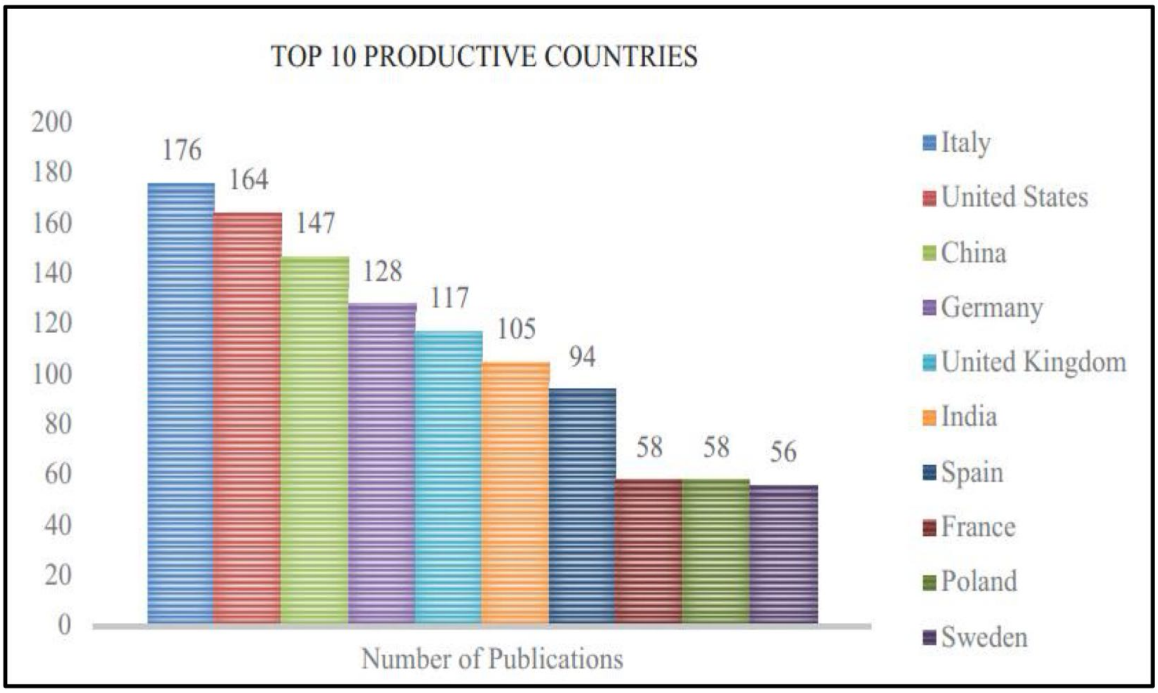
Source: author's own work

Figure- 2.7 Distribution of Publication for Industry 4.0



Source: author's own work

Figure- 2.8 Top Countries having Industry 4.0 publications



Source: Singh et al. (2024)

Total no of publications has crossed 1400 up till 2020 Business Management includes only 10% among the publications available for Industry 4.0 application. India is the 6th most productive for Industry 4.0 publications

Increased Flexibility and Responsiveness

Industry 4.0 enhances manufacturing flexibility by enabling real-time process monitoring. Companies can quickly adapt to market shifts and customer demands. For example, Xu, He, and Li (2018) found that IoT and AI integration supports agile production systems that minimize lead times and reduce inventory costs.

Improved Resource Utilization

Real-time monitoring of equipment performance optimizes resource utilization. Predictive maintenance strategies, enabled by big data analytics, identify potential failures before they occur, reducing downtime and enhancing operational efficiency (Brettel, Friederichsen, Keller, & Rosenberg, 2014; Kamble, Gunasekaran, & Sharma, 2020).

2.4.4 Challenges of Industry 4.0 Implementation

Workforce Skills Gap

Adopting Industry 4.0 requires an upskilled workforce proficient in data analytics, IoT, and AI. However, many organizations struggle with a skills gap, leading to resistance to change and hindering effective implementation (Bauernhansl, ten Hompel, & Vogel-Heuser, 2014).

Integration Issues

Integrating new Industry 4.0 technologies with legacy systems presents a significant challenge. The lack of interoperability can cause inefficiencies and increased costs, necessitating well-planned digital transformation strategies (Chiarini, 2021).

Cybersecurity Risks

The increased reliance on interconnected devices raises cybersecurity concerns. Many organizations lack robust security frameworks, making them vulnerable to data breaches (Bouras, Dey, & Adamopoulou, 2020). Strengthening cybersecurity measures is crucial for Industry 4.0 success.

2.4.5 Case Studies of Industry 4.0 Implementation

- **Siemens:** Siemens implemented IoT and AI to optimize manufacturing processes, significantly improving efficiency and reducing lead times. Digital twin technology enables real-time process simulations for continuous optimization (Siemens AG, 2020).

- **General Electric (GE):** GE utilizes predictive analytics to enhance maintenance schedules and reduce equipment failures, resulting in significant cost savings and operational improvements (GE Digital, 2021).

- **Bosch:** Bosch has integrated smart sensors for real-time monitoring, improving visibility into production processes and enabling timely adjustments based on demand fluctuations (Bosch Group, 2019).

2.4.6 Systematic Literature Review (SLR)

Why is SLR Selected?

SLR ensures a structured and unbiased approach to analyzing Industry 4.0 adoption in Production Planning and Control (PPC). It systematically filters relevant research, identifies gaps, and synthesizes findings to provide an evidence-based understanding.

SLR Methodology

1. **Defining Search Criteria:** Keywords like "Industry 4.0," "Production Planning and Control," and "Automobile Sector" guide the literature search.
2. **Database Selection:** Scopus, Web of Science, and IEEE Xplore are utilized.
3. **Inclusion/Exclusion Criteria:** Studies are filtered based on relevance, publication year, and quality.
4. **Critical Analysis:** Selected articles are reviewed to extract key findings and patterns.
5. **Synthesis of Findings:** The final synthesis highlights trends, research gaps, and future directions.

The integration of ELR and SLR provides a comprehensive perspective on Industry 4.0 in PPC. While Industry 4.0 presents significant opportunities for efficiency and adaptability, challenges such as workforce skills gaps, integration complexities, and cybersecurity risks must be addressed. This review highlights the need for ongoing research to refine best practices and enhance Industry 4.0 implementation in the Indian automobile sector.

Table 2.7- Summary of Literature Review on Industry 4.0 in Production Planning and Control (PPC)

Author(s) & Year	***Focus of Study***	***Key Findings***	***Shortcomings /Limitations***	***How This Research Aims to Address the Gaps***
Zhou et al. (2015)	Role of IoT in smart manufacturing.	IoT enhances real-time monitoring, data collection, and decision-making processes in manufacturing.	Focused primarily on IoT, ignoring other key Industry 4.0 technologies like AI and big data in PPC.	This research explores the integrated role of IoT, AI, and big data in enhancing PPC processes holistically.
Wang et al. (2016)	Impact of cyber-physical systems (CPS) in manufacturing.	CPS enhances automation and enables smart factories, leading to efficiency and agility in production.	Limited focus on how CPS directly impacts production planning, especially in the context of emerging markets like India.	This research addresses how CPS influences PPC specifically in Indian automobile manufacturing.
Tortorella et al. (2018)	Industry 4.0 in lean manufacturing practices.	Industry 4.0 complements lean practices, enabling enhanced flexibility and	Focused on Western markets, with limited applicability	This research focuses on the Indian context, considering unique

Author(s) & Year	***Focus of Study***	***Key Findings***	***Shortcomings /Limitations***	***How This Research Aims to Address the Gaps***
		waste reduction in manufacturing.	to the complexities of the Indian automobile industry.	challenges and market conditions.
Jazdi (2014)	Industrial automation with Industry 4.0 technologies.	Automation leads to enhanced operational efficiency, especially in repetitive and high-volume tasks.	Did not explore how automation can be integrated with human decision-making in PPC.	This research investigates how automation can complement human decision-making in PPC processes.
Ivanov et al. (2018)	Disruptions and resilience in Industry 4.0 supply chains.	Industry 4.0 technologies can improve supply chain resilience through better forecasting and adaptability.	Lacked a focus on PPC integration in specific industries like automobile manufacturing.	This study addresses how Industry 4.0 can improve PPC within the automobile supply chain in India.
Yin et al. (2017)	Data-driven approaches in smart	Big data analytics enable predictive maintenance and better resource allocation.	Overemphasis on technical aspects, with little focus on	This research emphasizes the balance between technical

Author(s) & Year	***Focus of Study***	***Key Findings***	***Shortcomings /Limitations***	***How This Research Aims to Address the Gaps***
	manufacturing systems.		organizational and human factors in implementation.	solutions and human factors in PPC transformation.
Kamble et al. (2020)	Industry 4.0 readiness in Indian manufacturing.	Found that Indian industries are slow in adopting Industry 4.0 but see potential in IoT and big data.	Lacked industry-specific insights into the automobile sector and detailed analysis of PPC practices.	This research focuses on the Indian automobile sector and provides a detailed study of PPC integration.
Mittal et al. (2019)	Smart factories and automation in India.	Automation can significantly improve production efficiency in Indian industries.	Focused on technical advancements but lacked insights into organizational readiness and human skills gaps.	This research addresses human skill gaps and organizational readiness for implementing PPC technologies.
Bahrin et al. (2022)	Integration of Industry 4.0 with supply	Industry 4.0 improves transparency, traceability, and	Focused on supply chains but did not	This research explores how Industry 4.0 can

Author(s) & Year	*Focus of Study*	*Key Findings*	*Shortcomings /Limitations*	*How This Research Aims to Address the Gaps*
	chain operations.	reduces lead times in supply chains.	analyze the integration of PPC systems in specific sectors like automobiles.	improve PPC and integrate with the automobile supply chain in India.
Ramesh & Joshi (2021)	AI-based predictive analytics in PPC.	AI can enhance forecasting and decision-making in production planning by improving accuracy and speed.	Limited real-world applications in the Indian context, especially in the automobile industry.	This study applies AI in PPC within Indian automobile manufacturing, providing real-world case studies.
Kumar et al. (2022)	Cybersecurity risks in Industry 4.0-enabled manufacturing.	Identified cybersecurity as a growing risk in the interconnected systems of Industry 4.0.	Lacked focus on specific mitigation strategies in critical sectors like automobile production.	This research includes analysis of cybersecurity measures needed for Industry 4.0 in the Indian automobile industry.
Chen & Pan, 2024 (arXiv)	Development of a flexible and adaptive	Introduced a framework integrating PDDL, POPF task planner, and	The study focuses on a theoretical	Aims to replace rigid production line plans with

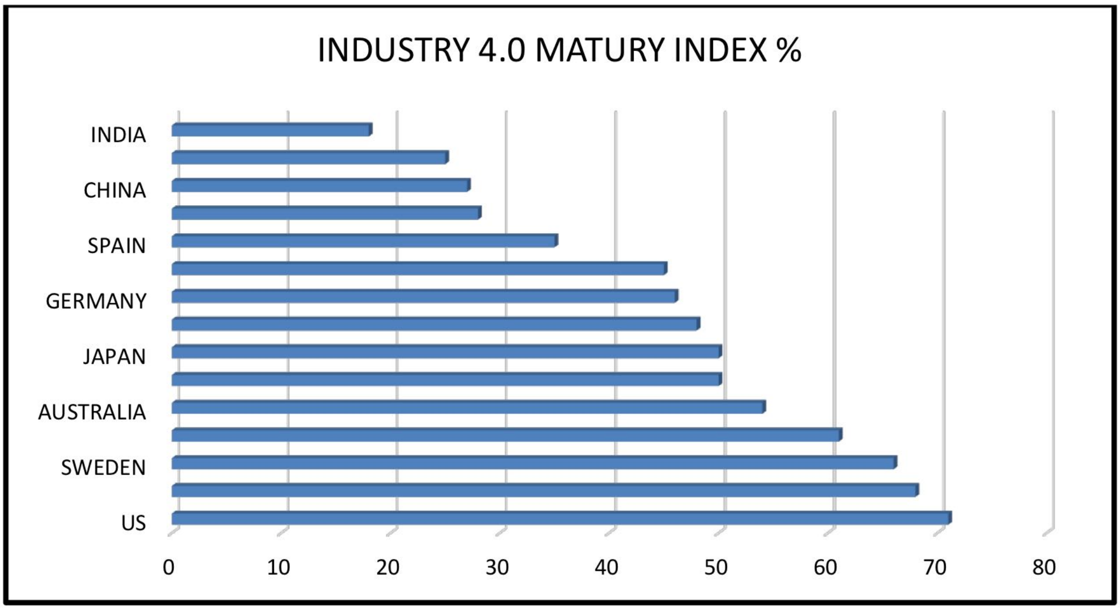
Author(s) & Year	***Focus of Study***	***Key Findings***	***Shortcomings /Limitations***	***How This Research Aims to Address the Gaps***
	framework for optimal task planning and agent-aware allocation in collaborative industrial scenarios.	a task allocation algorithm to generate optimal plans for collaborative robots and human workers.	framework; real-world applicability requires further testing.	flexible, adaptive frameworks in Industry 4.0 settings.
Windmann et al., 2024 (arXiv)	Review of integration challenges for Artificial Intelligence (AI) in Industry 4.0 industrial systems.	Identified key challenges: system integration, data-related issues, workforce management, and ensuring trustworthy AI.	The review highlights challenges but does not provide detailed solutions or implementation strategies.	Proposes avenues for future research to address integration challenges, aiding practitioners in evaluating AI adoption in Cyber-Physical Systems.
Production Planning & Control, 2024 (Taylor & Francis Online)	Various studies on production planning and control in the context of Industry 4.0.	Presented diverse research findings on integrating advanced technologies into production planning and control.	Compilation of studies; individual articles may have specific limitations.	Provides a comprehensive overview of current research trends and methodologies in the field.

Author(s) & Year	*Focus of Study*	*Key Findings*	*Shortcomings /Limitations*	*How This Research Aims to Address the Gaps*
Ferrari Group, 2024 (The Ferrari Group)	Importance of production planning and scheduling in the context of Industry 4.0.	Emphasized the critical role of advanced planning and scheduling in achieving operational efficiency.	Opinion-based article; lacks empirical data.	Highlights the need for integrating modern technologies to enhance production planning processes.
Metrology News, 2024 (Metrology News)	Transition from Industry 4.0 to Industry 5.0 focusing on scalable human-centric manufacturing.	Discussed the evolution towards more human-centric manufacturing approaches, emphasizing collaboration between humans and machines.	Conceptual discussion; lacks detailed implementation strategies.	Suggests a shift in focus towards enhancing human roles within advanced manufacturing systems.
Gembah, 2024 (Gembah)	Manufacturing trends shaping the future, including smart factories and AI integration.	Identified key trends such as increased AI integration, sustainability, and workforce evolution in manufacturing.	Broad overview; lacks specific focus on production planning and control.	Provides context on emerging trends that could influence future production planning strategies.
Applied Tech, 2024	Reasons for investing in	Outlined benefits such as improved efficiency,	Persuasive article; lacks	Encourages adoption of

Author(s) & Year	*Focus of Study*	*Key Findings*	*Shortcomings /Limitations*	*How This Research Aims to Address the Gaps*
(Applied Tech)	Industry 4.0 technologies by 2025.	competitiveness, and adaptability through Industry 4.0 investments.	empirical evidence.	Industry 4.0 technologies to stay competitive in the evolving manufacturing landscape.
Industry Science, 2024 (Industry Science)	Future outlook on production by 2025, focusing on technological advancements.	Predicted advancements in assistance systems improving work processes and increasing workplace flexibility.	Speculative outlook: actual developments may vary.	Provides a vision for future production environments, guiding strategic planning.
Deloitte Insights, 2024 (Deloitte)	Outlook on the manufacturing industry for 2025, considering Industry 4.0 advancements.	Anticipated continued challenges and uncertainties, emphasizing the need for technological adoption.	General industry outlook; not specific to production planning and control.	Highlights the importance of embracing Industry 4.0 technologies to navigate future challenges.
Plataine, 2024 (Plataine)	Key digital manufacturing trends shaping 2025, including the transition to Industry 5.0.	Discussed the extension of Industry 4.0 strengths into Industry 5.0, promoting human-centric operations.	Forward-looking perspective: actual trends may differ.	Suggests focusing on human-machine collaboration to enhance future production

Author(s) & Year	***Focus of Study***	***Key Findings***	***Shortcomings /Limitations***	***How This Research Aims to Address the Gaps***
				planning and control.

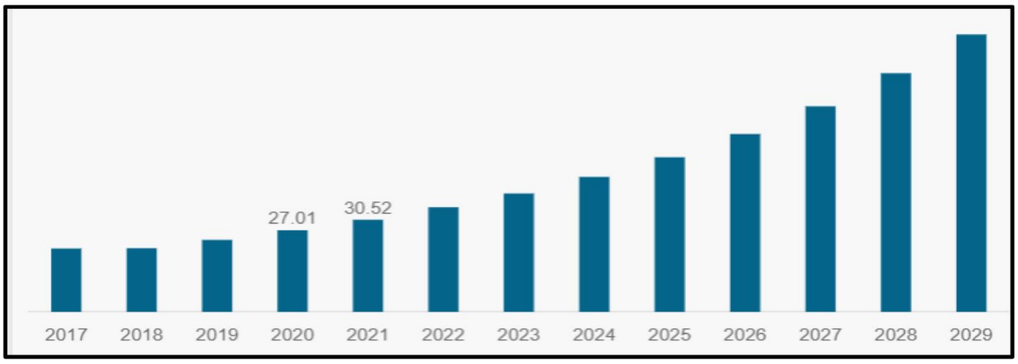
Figure2.9 Industry 4.0 Maturity in top countries



Source: Singh et al. (2024)

Industry 4.0 Market size has exponentially increased and tends to increase by the time. Globally market size of Industry 4.0 in the world mapped from 2017 to 2021 was up till 30.52 USD Billion average of all countries which is very huge.

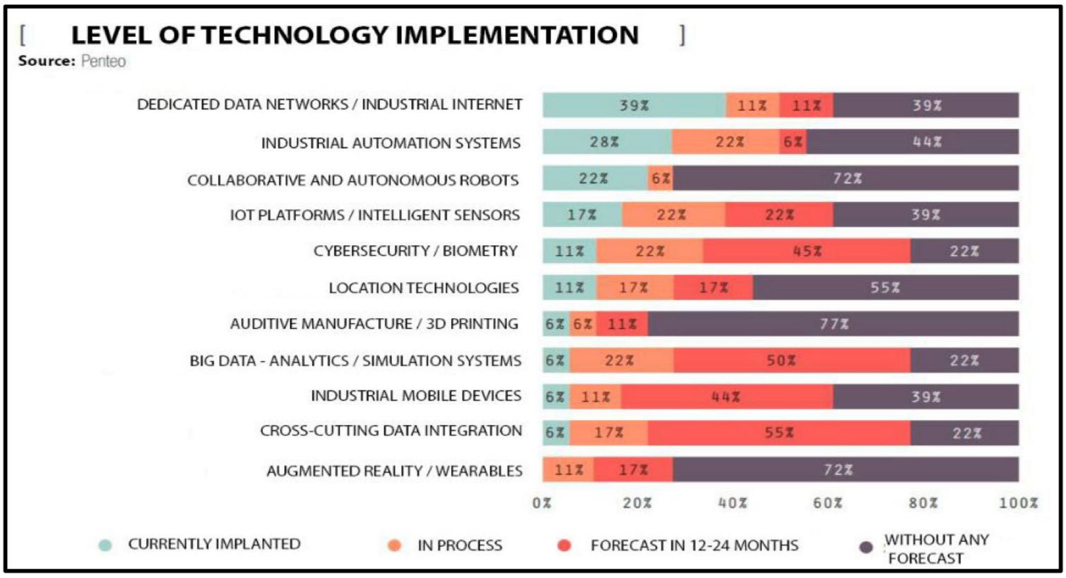
Figure2.10 Level of implementation of Industry 4.0 year wise



Source: Singh et al. (2024)

If we find the level of implementation of this technology across the globe, then we find that all the tools of Industry 4.0 are penetrating into the world seamlessly and swiftly. Industrial internet has crossed 39%of total population and 22% more to rise in due course. After pandemic implementation of these technologies and interdependence of machines and technology has increased substantially

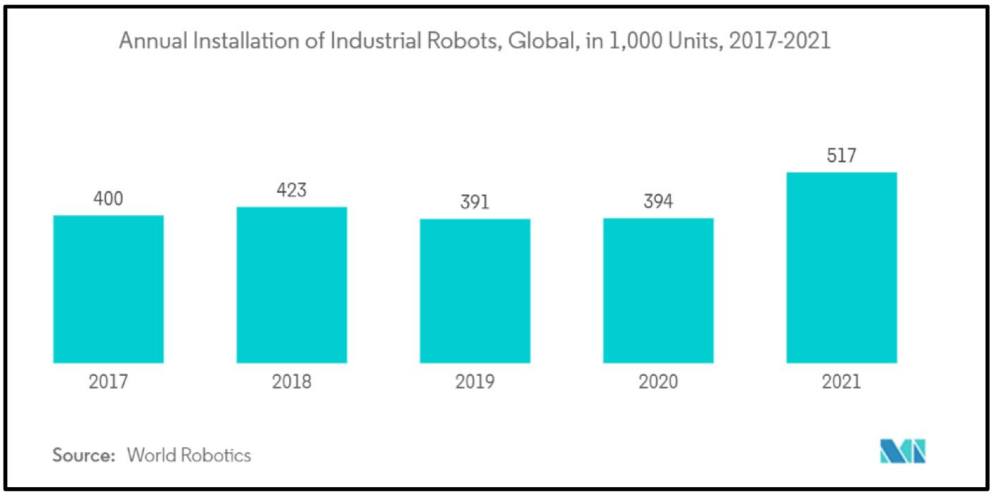
Figure2.11 Level of Industry 4.0 tools maturation and implementation



Source: Singh et al. (2024)

If we find the trend where annual installation of Industrial robots, we find that average of 400 shooted up to 500+ after pandemic which clearly indicated the requirement of Industry 4.0 in the industries.

Figure2.12 Robo installation rate in World



Source: Singh et al. (2024)

Industry which represents a significant transformation in the manufacturing sector, characterized by the integration of advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data analytics, and cyber-physical systems. This literature review aims to explore the implications of Industry 4.0 on production planning and control, focusing on how these technologies can optimize processes, improve decision-making, and enhance overall operational efficiency.

Theoretical Framework of Industry 4.0- The term "Industry 4.0" was first introduced in Germany as part of a high-tech strategy to promote the computerization of manufacturing (Kagermann et al., 2013). It emphasizes the creation of smart factories where machines, systems, and humans communicate and cooperate in real-time. The underlying technologies include IoT, cloud computing, AI, and advanced robotics, all of which contribute to increased automation, flexibility, and efficiency in production environments (Mourtzis et al., 2016).

Technological Components of Industry 4.0- Internet of Things (IoT) IoT is a foundational component of Industry 4.0, enabling devices and machines to connect and share data seamlessly. This connectivity allows for real-time monitoring of production processes, facilitating timely decision-making and operational adjustments (Li et al., 2018). For instance, smart sensors can track equipment performance, alerting managers to potential issues before they escalate (Wang et al., 2016). Big Data and Analytics The integration of big data analytics into production planning enables organizations to process vast amounts of data generated by IoT devices. Predictive analytics can be employed to forecast demand, optimize inventory levels, and improve scheduling accuracy (Kumar & Singh, 2021). Studies show that organizations leveraging big data analytics achieve significant improvements in efficiency and responsiveness (Müller et al., 2021). Cyber-Physical Systems (CPS) CPS combines physical processes with computational resources, allowing for a more interconnected and intelligent production environment. By utilizing CPS, manufacturers can create digital twins—virtual replicas of physical systems that can simulate, predict, and optimize performance (Tao et al., 2018). This capability is particularly beneficial for production planning, as it enables organizations to test various scenarios and make informed decisions based on simulations.

Case-Studies of Industry 4.0 Implementation Several organizations have successfully implemented Industry 4.0 technologies in their production planning and control processes: Siemens has adopted Industry 4.0 principles to optimize its manufacturing operations. By implementing IoT and AI, Siemens has enhanced its production processes, achieved significant efficiency gains and reduced lead times (Siemens AG, 2020). The company's digital twin technology enables real-time simulations, allowing for continuous process optimization. General Electric (GE) General Electric leverages predictive analytics to improve maintenance schedules and reduce equipment failures. By utilizing big data to analyse performance metrics, GE has enhanced its operational efficiency, resulting in significant cost savings (GE Digital, 2021). This case illustrates how Industry 4.0 technologies can drive tangible benefits in production planning. Bosch has integrated smart sensors into its manufacturing processes, enabling real-time monitoring and control. This implementation has improved visibility into production processes, allowing for timely adjustments based on demand fluctuations (Bosch Group, 2019). The company's commitment to Industry 4.0 demonstrates the potential for enhanced efficiency and competitiveness. Integration of Sustainability Future research should investigate how Industry 4.0 technologies can be aligned with sustainability initiatives. As environmental concerns grow, integrating sustainable practices into production planning and control is critical (Müller et al., 2021). Understanding how digital technologies can contribute to sustainable manufacturing will be vital for future research. Addressing Workforce Development Research should also focus on strategies for workforce development in the context of Industry 4.0. Understanding the skills required for successful implementation and developing training programs to address the skills gap will be essential for organizations transitioning to smart manufacturing environments. Enhancing Cybersecurity Frameworks Given the increasing reliance on connected devices, future research should prioritize the development of robust cybersecurity frameworks tailored to Industry 4.0 environments. Investigating best practices and effective strategies to mitigate cybersecurity risks will be crucial for organizations aiming to protect their data and systems. Adopting Industry 4.0 technologies in production planning and control presents substantial opportunities to improve efficiency, adaptability, and decision-making processes. However, obstacles such as skill shortages, integration complexities, and cybersecurity concerns need to be tackled to ensure successful implementation. This review highlights the importance of ongoing research to identify innovative strategies and best practices for utilizing Industry 4.0 to achieve excellence in manufacturing. While more recent literature has started addressing Industry 4.0 applications in emerging markets like India, several gaps remain:

- **Lack of sector-specific focus**: Recent studies often discuss Industry 4.0 in a broad sense, but do not drill down into specific industries like the automobile sector. This creates a gap in understanding how these technologies can be customized for the automobile industry.
- **Organizational and human factors**: While recent literature highlights the technological advancements brought by Industry 4.0, there is still limited

attention given to how organizations, employees, and existing systems can be aligned with these advancements, especially in Indian firms.

- **Cybersecurity and risk management**: The issue of cybersecurity has gained attention, but studies on its implications in Industry 4.0-enabled PPC systems, particularly in critical sectors like automobiles, are scarce.

How this Research Fills the Gaps:

- **Automobile industry focus**: This research provides an in-depth study of Industry 4.0 technologies in the context of production planning and control in the Indian automobile industry, addressing the need for industry-specific analysis.
- **Organizational readiness and human factors**: The research aims to study not just the technological adoption of Industry 4.0 but also how organizations and employees adapt, focusing on skills development, changing management, and employee integration.
- **Cybersecurity and risk management in PPC**: By incorporating cybersecurity analysis, this research will examine the risks and potential vulnerabilities that arise from interconnected systems in Industry 4.0 and propose strategies for mitigating these risks.

2.5.Significant Learning from Literature Survey

The literature survey has provided several key insights into the application of Industry 4.0 in Production Planning and Control (PPC) within the context of the Indian automobile industry. The following significant findings emerged from the review:

1. **Readiness Factors for Industry 4.0 Adoption**: A recurring theme in the literature is the identification of readiness factors that influence the successful adoption of Industry 4.0 technologies. These include technological infrastructure, organizational culture, leadership commitment, employee skill levels, and alignment with business strategy. The literature highlights the importance of assessing these factors early to ensure smooth implementation and avoid disruptions in production processes.

2. **Catalysts for Industry 4.0 Implementation**: The literature reveals that several catalysts drive the adoption of Industry 4.0 technologies in PPC, including the need for improved operational efficiency, cost reduction, quality control, and real-time data usage. Advances in technologies such as Internet of Things (IoT), Artificial Intelligence (AI), and Big Data analytics have emerged as critical enabling in reshaping traditional manufacturing processes, allowing for more flexible and automated production systems.

3. **Impediments to Implementation**: Despite the promising benefits, literature also highlights several impediments to the adoption of Industry 4.0. These include high initial investments, complexity of integrating new technologies with existing systems, data security concerns, and resistance to change within organizations. Addressing these barriers requires comprehensive planning, training, and collaboration across various departments within the organization.

4. **Contextual Relationships Among Catalysts and Impediments**: Analyzing the interactions between catalysts and impediments has provided valuable insights into how they influence each other in the implementation process. For instance, while technological advancements (a catalyst) may facilitate the integration of Industry 4.0, lack of skilled labor (an impediment) could hinder its successful deployment. Understanding these relationships can help organizations identify critical areas for intervention and streamline the adoption process.

5. **Prioritization of Critical Factors**: Through the review, it became evident that not all factors are equally important in determining the success of Industry 4.0 adoption. By prioritizing the critical catalysts and impediments, organizations can focus their efforts on the most impactful areas, ensuring a higher return on investment. Various Multi-Criteria Decision-Making (MCDM) techniques, such as Fuzzy Best-Worst Method (BWM), have been identified as effective tools for prioritizing these factors.

6. **Emerging Trends in Industry 4.0 Applications**: The survey also identified emerging trends in Industry 4.0 applications, such as the integration of cyber-

physical systems (CPS), blockchain for supply chain transparency, and the use of autonomous robots in production lines. These innovations hold great potential for transforming production planning and control, but they also require organizations to adopt a long-term vision and strategy.

In conclusion, the literature survey has provided a comprehensive understanding of the current landscape of Industry 4.0 in the Indian automobile sector. It has not only highlighted the critical success factors but also underscored the challenges that need to be addressed to realize the full potential of Industry 4.0 in PPC.

Chapter-3

RESEARCH METHODOLOGY

Chapter Overview

This chapter includes the selection of research methodologies for fulfilling the gaps and clarifies why this methodology is best suited for the approaches with their advantages over other methodologies. This chapter includes detailed discussion of each methodology selected for the research work. This section focuses on the philosophy of research followed by data collection methods along with all statistical calculations performed. This chapter shows the table for research gap and research questions with their objectives and outcomes for the complete research work.

3.1.Introduction

This chapter details the methodology adopted to investigate the implementation of Industry 4.0 in production planning and control (PPC) within the Indian automobile industry. The primary goal of this research is to identify, analyze, and prioritize the factors influencing the adoption of Industry 4.0 technologies. This involves an exploration of the enablers and barriers to its successful implementation. A blend of both qualitative and quantitative research techniques is applied, utilizing advanced tools such as Fuzzy Delphi, Multi-Criteria Decision-Making (MCDM), and Fuzzy Interpretive Structural Modelling (Fuzzy ISM) to ensure a comprehensive and reliable analysis.

The research incorporates the following key approaches:

- **Fuzzy Delphi Method (FDM)**: To achieve consensus among industry experts on critical factors.
- **Fuzzy COPRAS**: To evaluate the readiness of the automobile industry for Industry 4.0 adoption.
- **Fuzzy Best-Worst Method (BWM)**: To prioritize enablers and barriers.

- **Fuzzy ISM**: To explore the contextual relationships between identified enablers and impediments.

Here's a detailed explanation of why these methods is appropriate and their benefits compared to other techniques.

3.1.1 Fuzzy Delphi Method (FDM)

Why FDM is Selected:

Expert-Driven Consensus: FDM is ideal when dealing with complex, uncertain, or subjective issues, like assessing the readiness factors for Industry 4.0. It gathers expert opinions iteratively, refining the results through rounds of feedback.

Handling Ambiguity: Automobile industries' readiness for Industry 4.0 can involve ambiguous factors. Fuzzy Delphi incorporates the Fuzzy logic concept, which allows for handling the uncertainty and vagueness inherent in expert opinions and readiness metrics.

Refining Factors: FDM is excellent for narrowing down large lists of possible readiness factors, refining them based on expert consensus to a set of cores, actionable criteria relevant to Industry 4.0 adoption in production planning.

Advantages Over Other Techniques:

Combines Delphi's Consensus with Fuzzy Logic’s Ambiguity Handling: Traditional Delphi methods do not account for the ambiguity and vagueness in expert opinions. Fuzzy Delphi adds this layer, making it more suitable for areas with uncertainty, like readiness assessment.

Efficient Expert Input: Unlike simple surveys or interviews, FDM iteratively refines expert opinions, ensuring that the final list of readiness factors is a product of consensus among industry leaders.

Improved Accuracy: By incorporating fuzziness, FDM handles the imprecise nature of human judgments better than techniques such as simple questionnaires or surveys.

Iterative Feedback: FDM allows for refining the factors based on expert responses over several rounds, ensuring the best possible input for your readiness factors.

3.1.2 Fuzzy COPRAS Method

Why Fuzzy COPRAS is Selected:

Multi-Criteria Decision Making (MCDM): Fuzzy COPRAS (COmplex PRoportional ASsessment) is specifically designed for multi-criteria decision-making in environments that involve subjective evaluation and uncertain data, making it ideal for evaluating Industry 4.0 readiness.

Ranking Readiness Factors: Once readiness factors are identified through Fuzzy Delphi, Fuzzy COPRAS can be used to rank them according to their importance, helping to prioritize the factors most critical for the successful implementation of Industry 4.0 in Production Planning and Control.

Proportional Analysis: Fuzzy COPRAS assesses alternatives proportionally to both the positive and negative ideal solutions, meaning it doesn't just look at the best or worst cases but provides a balanced ranking of all alternatives.

Handles Ambiguity in Decision-Making: Fuzzy COPRAS introduces fuzziness to account for uncertainty and vagueness in decision-making, which is common when evaluating technological readiness in a fast-evolving field like Industry 4.0.

Advantages over other techniques:

Better Decision-Making Under Uncertainty: Compared to traditional decision-making techniques like AHP (Analytic Hierarchy Process) or TOPSIS, Fuzzy COPRAS offers better flexibility and precision when handling subjective and uncertain data, making it more suitable for complex, real-world scenarios like Industry 4.0 readiness.

Prioritization of Multiple Criteria: Unlike single-factor methods, Fuzzy COPRAS excels in environments where multiple criteria (e.g., technological readiness, organizational culture, financial resources) must be considered simultaneously, which is crucial for implementing Industry 4.0.

Proportionality: It offers a more balanced evaluation by considering both positive and negative attributes proportionally, unlike simpler methods that may only focus on maximizing positive outcomes.

Comprehensive Ranking: Fuzzy COPRAS ranks readiness factors from best to worst in a comprehensive manner, providing detailed insight into the most critical factors that require attention.

Conclusion:

By selecting SLR, Fuzzy Delphi, and Fuzzy COPRAS, your research methodology combines the strengths of: A thorough and unbiased review of existing knowledge (SLR), Expert-driven refinement of readiness factors (Fuzzy Delphi), and A robust, multi-criteria decision-making tool for ranking and analysing those factors (Fuzzy COPRAS). These methodologies provide a significant advantage over simpler or more traditional methods by ensuring that your analysis is thorough, adaptable to ambiguity, and capable of handling complex, multi-faceted decision-making processes. This approach aligns perfectly with the goal of assessing the industry 4.0 readiness of automobile industries, which is a complex and evolving area that requires nuanced and flexible research techniques.

The use of the Fuzzy Best-Worst Method (Fuzzy BWM) to prioritize the critical catalysts and impediments for the implementation of Industry 4.0 in Production Planning and Control within the automobile industry is highly justified due to several key reasons and its advantages over other techniques.

3.1.3 Fuzzy Best-Worst Method (Fuzzy BWM)

Reasons for Selection:

Pairwise Comparison and Prioritization: The BWM allows for pairwise comparison between critical factors (catalysts and impediments), making it ideal for prioritizing them. It enables decision-makers to determine which factors are more significant, ensuring a more accurate prioritization of readiness factors.

Efficiency in Decision Making: By asking decision-makers to identify the "best" (most influential) and "worst" (least influential) factors, Fuzzy BWM reduces the complexity associated with traditional multi-criteria decision-making (MCDM) methods, while still yielding reliable results.

Handling of Uncertainty: The fuzzy extension of BWM addresses the inherent uncertainty and vagueness in human judgment, especially when decision-makers may not be confident in expressing crisp values. The fuzzy component allows for greater flexibility and a more accurate reflection of real-world decision-making environments.

Accurate Weighting: Fuzzy BWM delivers optimal weight determination, which is crucial for correctly identifying the importance of each catalyst and impediment in the context of Industry 4.0 implementation.

Advantages over other Techniques:

Reduced Inconsistency: Compared to Analytic Hierarchy Process (AHP) and other ranking methods, BWM requires fewer comparisons (only between best and worst elements), which reduces the risk of inconsistency in judgments. This is particularly beneficial when analysing a large set of catalysts and impediments.

Simplified Decision Process: Traditional MCDM methods like AHP or TOPSIS require more extensive pairwise comparisons and are more computationally complex. Fuzzy BWM simplifies the decision process by focusing on the most and least critical factors, making it less time-consuming and more practical for prioritization tasks.

Improved Reliability: Fuzzy BWM's structured comparison approach leads to more consistent and reliable judgments compared to methods that involve an overwhelming number of comparisons. This ensures that the priorities identified for Industry 4.0 catalysts and impediments are more dependable.

Suitability for Complex Environments: The fuzzy logic extension in BWM makes it particularly suited for dealing with the complexities of Industry 4.0, where data may be imprecise, uncertain, or incomplete. This allows decision-makers to express their preferences more naturally and intuitively.

Comparison with Other Techniques

Advantages over AHP (Analytic Hierarchy Process):

Fewer Pairwise Comparisons: AHP requires a large number of pairwise comparisons, especially as the number of criteria grows. This increases the likelihood of inconsistency in the decision-making process. Fuzzy BWM requires far fewer comparisons, improving consistency.

Reduced Subjectivity: AHP can become subjective, especially when multiple criteria are involved. Fuzzy BWM reduces the subjectivity by focusing only on the best and worst factors and leveraging fuzzy logic to accommodate uncertainty in the decision-maker's judgments.

Advantages over TOPSIS (Technique for Order Preference by Similarity to Ideal Solution):

Direct Weight Optimization: Fuzzy BWM focuses on direct optimization of weights for the criteria (catalysts and impediments), while TOPSIS ranks alternatives based on distance from an ideal solution. Fuzzy BWM's weight determination process is more accurate and straightforward, making it better suited for priority determination in complex environments like Industry 4.0.

Less Sensitivity to Data Scaling: Unlike TOPSIS, which can be sensitive to data scaling and normalization, Fuzzy BWM is more robust in situations with imprecise or vague input data. This makes it more practical for handling real-world industrial scenarios, where data is often ambiguous.

Advantages over Fuzzy AHP:

Better Consistency: While Fuzzy AHP incorporates fuzzy logic, it still involves multiple pairwise comparisons for each criterion, which can lead to inconsistency in judgments. Fuzzy BWM minimizes the comparison process and focuses on the most important elements, leading to more reliable results.

Simpler Application: Fuzzy AHP can become cumbersome with a large number of factors. Fuzzy BWM, on the other hand, is simpler and more focused, making it more practical for prioritizing a list of critical catalysts and impediments.

Advantages over Other Multi-Criteria Decision-Making (MCDM) Methods:

Greater Flexibility in Uncertainty Handling: Methods like Simple Additive Weighting (SAW) or VIKOR often lack the ability to incorporate uncertainty and vagueness in human judgments. Fuzzy BWM's use of fuzzy logic gives decision-makers the flexibility to express uncertainty, leading to more realistic prioritization.

More Reliable Prioritization: Fuzzy BWM delivers a more reliable prioritization of critical factors compared to simpler MCDM methods, as it offers a clear structure for determining the best and worst criteria and optimally calculating their weights.

Specific Advantages in the Context of Industry 4.0 for Automobile Industries

Tailored for Complex, Emerging Technologies: Industry 4.0 involves multi-dimensional factors such as technological infrastructure, workforce readiness, and digital transformation. Fuzzy BWM, with its ability to handle complex relationships and uncertainty, is well-suited for prioritizing these catalysts and impediments.

Real-World Applicability: In the fast-evolving and uncertain landscape of Industry 4.0, the fuzzy logic component of BWM makes it more adaptable to the dynamic nature of automobile industries, ensuring that the prioritization of critical factors is aligned with real-world scenarios.

Optimal Use of Resources: In production planning and control, focusing on the right catalysts and mitigating impediments is crucial for successful implementation. Fuzzy BWM enables organizations to allocate resources more effectively, ensuring that they focus on the most impactful areas for Industry 4.0 implementation.

Conclusion:

The Fuzzy Best-Worst Method is ideal for prioritizing the critical catalysts and impediments in the implementation of Industry 4.0 in the production planning and control of automobile industries. It offers superior accuracy, efficiency, and reliability compared to other techniques. By focusing on pairwise comparisons between the best and worst factors and incorporating fuzzy logic to address uncertainty, it ensures a robust, flexible, and practical approach to decision-making in complex industrial environments.

The use of Fuzzy Interpretive Structural Modelling (Fuzzy ISM) to analyse the contextual relationship among the identified catalysts and impediments for the implementation of Industry 4.0 in Production Planning and Control in the automobile industry is a well-justified choice for several reasons. It offers numerous advantages over other techniques, particularly in understanding and mapping the relationships between these critical factors.

3.1.4 Fuzzy Interpretive Structural Modeling (Fuzzy ISM)

Reasons for Selection:

Identification of Hierarchical Relationships: Fuzzy ISM is specifically designed to identify and map the contextual relationships between factors (in this case, catalysts and impediments) in a hierarchical structure. This makes it ideal for understanding how different elements influence one another and determining the most critical drivers and barriers in implementing Industry 4.0.

Modelling Interdependence and Influence: ISM helps depict complex interrelationships among the identified factors by constructing a directed graph or digraph that shows how different catalysts and impediments affect one another. Fuzzy ISM enhances this by incorporating fuzzy logic, which allows for handling uncertainty and ambiguity in the relationship strength between factors.

Better Representation of Real-World Complexity: The fuzzy component allows decision-makers to express relationships in degrees of influence rather than binary (yes/no) terms. This is crucial in real-world scenarios like Industry 4.0 implementation, where relationships among factors are not always absolute or certain.

Advantages over Other Techniques:

Structured and Systematic Analysis: Fuzzy ISM provides a structured, step-by-step process for analysing complex relationships, starting from pairwise comparisons of factors to the construction of a hierarchical model. This structured approach offers better insights into how catalysts and impediments interact within the industry 4.0 framework, compared to simpler methods like basic correlation analysis.

Handling Vague and Uncertain Information: Unlike traditional ISM, which deals with clear and direct relationships, Fuzzy ISM accounts for the inherent uncertainty in decision-makers' judgments, especially when the relationships between catalysts and impediments are not well defined. This makes it particularly useful in analysing complex, dynamic environments like Industry 4.0 in the automobile sector, where decision-makers may have only partial or fuzzy knowledge about the interconnections.

Visualization of Influence: Fuzzy ISM allows for the visualization of relationships in a clear, hierarchical manner through directed graphs. This helps in not only understanding the relationships but also in strategizing actions based on the most critical and influential factors.

Advantages over Other Techniques

Advantages over Traditional ISM:

Enhanced Precision through Fuzzy Logic: Traditional ISM uses binary relationships to assess whether one factor influences another. However, this can oversimplify the analysis. Fuzzy ISM allows for the assessment of relationships on a spectrum, offering a more nuanced and precise understanding of how catalysts and impediments influence each other.

Reduced Subjectivity: Traditional ISM can be subjective due to its binary nature. Fuzzy ISM minimizes subjectivity by using fuzzy logic to quantify the degree of influence, allowing for a more accurate representation of the real-world interdependencies among Industry 4.0 factors.

2. Advantages over DEMATEL (Decision-Making Trial and Evaluation Laboratory):

Hierarchical Structure vs. Network Representation: DEMATEL provides a network representation of relationships but does not organize the factors in a hierarchical structure, which is essential when you need to identify the root causes or most influential factors. Fuzzy ISM helps structure the relationships hierarchically, providing a clearer understanding of the relative importance of catalysts and impediments.

More Focused on Hierarchies: DEMATEL's network approach can sometimes make it difficult to clearly identify key driving factors or impediments. Fuzzy ISM, by contrast, explicitly organizes these relationships into hierarchical levels, which is more useful for planning and decision-making in complex systems like Industry 4.0.

Advantages over MICMAC Analysis:

Detailed Contextual Relationships: MICMAC (Matrix of Cross-Impact Multiplications Applied to Classification) is often used alongside ISM to analyse the driving and dependence power of factors, but it doesn't provide the same level of detail regarding contextual relationships. Fuzzy ISM not only reveals which factors are drivers or dependent variables but also maps their relationships in a more structured, detailed way.

Less Complexity: MICMAC requires extensive cross-impact matrix analysis, which can be computationally intensive. Fuzzy ISM is relatively easier to implement and interpret, especially when analysing complex systems with numerous interrelated factors.

Advantages over AHP (Analytic Hierarchy Process):

Better Representation of Interdependencies: AHP assumes that the criteria are independent, which is often not the case in complex systems like Industry 4.0. Fuzzy ISM, on the other hand, is specifically designed to model interdependencies between factors, making it more suitable for analysing how catalysts and impediments influence each other.

Fewer Comparisons Needed: AHP involves numerous pairwise comparisons and becomes cumbersome as the number of factors increases. Fuzzy ISM requires fewer comparisons and provides a more streamlined process for understanding the influence structure among catalysts and impediments.

3.Specific Advantages in the Context of Industry 4.0 for Automobile Industries

Clear Identification of Key Drivers and Barriers: In Industry 4.0, some catalysts may act as key enablers, while certain impediments may be root barriers. Fuzzy ISM helps in identifying these key drivers and barriers by structuring the factors in a hierarchical manner. This clarity is crucial for decision-making in production planning and control, where prioritizing the most critical factors can significantly impact the success of Industry 4.0 initiatives.

Improved Decision-Making: By revealing the hierarchical structure of the catalysts and impediments, Fuzzy ISM allows industry leaders to make better-informed decisions on which areas to focus on first when implementing Industry 4.0 technologies in production planning and control.

Adaptability to Dynamic Environments: The automobile industry is dynamic and rapidly evolving, particularly with the integration of Industry 4.0 technologies. Fuzzy ISM provides greater flexibility in capturing the nuances of this dynamic environment, making it easier for organizations to adapt their strategies based on evolving relationships between catalysts and impediments.

4. Comparison with Other Methods for Relationship Analysis

Advantages over Structural Equation Modelling (SEM):

Qualitative Focus: SEM is more suited for quantitative analysis of relationships, requiring large datasets and statistical validation. Fuzzy ISM, by contrast, focuses on qualitative assessment of relationships, making it more suitable for early-stage research or when dealing with limited data and expert opinions, as is often the case in Industry 4.0 readiness studies.

Less Data-Intensive: SEM requires a large sample size and rigorous statistical validation, which can be difficult to obtain when analysing catalysts and impediments in a niche area like Industry 4.0. Fuzzy ISM, with its qualitative and fuzzy logic approach, is less data-intensive, making it more practical for this kind of research.

Advantages over Cause-Effect Analysis (Fishbone Diagram):

Incorporation of Fuzziness: While cause-effect analysis identifies broad relationships, it does not capture the degree of influence, or the uncertainty involved. Fuzzy ISM excels at quantifying the strength of relationships between factors, providing a more detailed and accurate understanding of the system.

Structured Representation: Fishbone diagrams provide a simple, flat view of relationships, whereas Fuzzy ISM organizes relationships in a hierarchical and structured manner, making it easier to pinpoint the most influential catalysts and impediments.

Conclusion:

Fuzzy ISM is the ideal method for analysing the contextual relationships among catalysts and impediments for the implementation of Industry 4.0 in production planning and control of automobile industries. Its ability to handle complex interdependencies, account for fuzzy and uncertain data, and organize factors in a hierarchical structure provides superior insights compared to other techniques. Fuzzy ISM offers a systematic, flexible, and accurate approach, making it an invaluable tool for strategic decision-making in the complex landscape of Industry 4.0.

3.2. Research Philosophy

The research philosophy of this study is **pragmatism**, which emphasizes the use of practical approaches to problem-solving. Pragmatism allows the integration of both qualitative and quantitative data to derive actionable insights, which can directly aid in the effective adoption of Industry 4.0 technologies in PPC within the Indian automobile sector.

- **Ontological Perspective**: This study recognizes that there are multiple realities, especially in the realm of adoption of technology. Different companies may face unique challenges due to varying organizational cultures, infrastructure levels, and financial capacities.
- **Epistemological Perspective**: A balance between theoretical and practical knowledge is maintained. Expert opinions gathered through methods like the Fuzzy Delphi are combined with quantitative data to form comprehensive insights.
- **Axiological Perspective**: The research places high value on actionable, real-world insights that can lead to practical improvements in production planning and control through Industry 4.0 technologies.

3.3.Data Collection

3.3.1 Primary Data Collection

Fuzzy Delphi Study

The primary data collection for this study involves the use of the Fuzzy Delphi method, which is particularly effective in deriving consensus from a group of experts on complex topics. This approach is well-suited for identifying and validating critical factors influencing the adoption of Industry 4.0 in production planning and control (PPC).

The Fuzzy Delphi study integrates the traditional Delphi method with fuzzy logic to quantify subjective expert opinions, addressing the inherent ambiguity and uncertainty in qualitative data. It is widely recognized for its ability to generate reliable and precise outcomes in decision-making and evaluation scenarios. This method ensures that the readiness factors, enablers, and barriers to Industry 4.0 implementation are identified and validated systematically.

- **Target Group**: The study targets a diverse group of experts, including:
    - **Professionals from Tier 1 and Tier 2 Suppliers**: These participants provide insights into supply chain dynamics and operational challenges.
    - **Original Equipment Manufacturers (OEMs)**: OEMs offer perspectives on production planning and strategic implementation of advanced technologies.
    - **Technology Consultants**: These experts contribute knowledge on technological solutions and industry best practices.
    - **Academic Experts**: Researchers specializing in Industry 4.0 and PPC provide theoretical frameworks and validation.

- **Purpose**: The primary objectives of the Fuzzy Delphi study are:
    - To identify and validate readiness factors, catalysts, and impediments specific to Industry 4.0 adoption in PPC.
    - To establish a prioritized list of factors that can guide stakeholders in overcoming challenges and leveraging opportunities.
- **Procedure**:
    1. **Expert Selection**: Experts are chosen based on their experience and relevance to the Indian automobile sector.
    2. **Initial Questionnaire**: An initial survey is distributed to gather opinions on various factors.
    3. **Fuzzy Logic Analysis**: Responses are processed using fuzzy logic to quantify and analyze opinions.
    4. **Iterative Feedback**: Experts review the aggregated results and refine their input in subsequent rounds.
    5. **Consensus Building**: The process continues until a consensus is achieved on the critical factors.

The Fuzzy Delphi study ensures that the collected data is both comprehensive and actionable, providing a robust foundation for the subsequent analysis and framework development.

3.3.2 Secondary Data Collection

The secondary data collection employs a Systematic Literature Review (SLR) to gather and analyze existing knowledge on Industry 4.0 implementation in PPC. The SLR method is meticulous and structured, ensuring that only high-quality and relevant literature is included.

- **Sources**: The SLR draws from a wide range of credible sources, including:

- **Peer-reviewed Journals**: Articles from reputed journals ensure academic rigor.
- **Industry White Papers**: These provide practical insights and case studies from industry.
- **Government Reports**: Policy documents and industry guidelines highlight macro-level trends and challenges.
- **Conference Proceedings**: Emerging research and innovative solutions are explored through recent conference papers.

- **Data Points**: The key data points extracted from the literature include:
  - **Technology Adoption Trends**: Insights into global and regional trends in Industry 4.0 technologies.
  - **Case Studies**: Examples of successful and failed implementations provide practical lessons.
  - **Theoretical Frameworks**: Existing models and methodologies for Industry 4.0 integration.
  - **Barriers and Enablers**: Identification of critical challenges and driving factors.
  - **Impact on PPC**: Analysis of how Industry 4.0 affects production planning and control processes.

Integration of Primary and Secondary Data

The integration of primary and secondary data ensures a holistic approach to understanding the adoption of Industry 4.0 in PPC. While the Fuzzy Delphi study provides real-world insights from industry practitioners, the SLR complements this by offering a comprehensive theoretical and empirical background. Together, these methodologies create a robust framework for addressing the research objectives and formulating practical recommendations for the Indian automobile industry.

3.4 Methodological Framework

3.4.1 Identifying and Analyzing Readiness Factors

- **Method**: Systematic Literature Review, Fuzzy Delphi, and Fuzzy COPRAS.
- **Objective**: The readiness of the Indian automobile industry for Industry 4.0 adoption in production planning and control is analyzed. A systematic review identifies existing literature on readiness factors, and the Fuzzy Delphi method collects expert opinions to refine these factors. Fuzzy COPRAS (Complex Proportional Assessment) is then applied to evaluate and rank these factors based on criteria such as technological infrastructure, human resources, and financial investment.

3.4.2 Finding Critical Catalysts and Impediments

- **Method**: Systematic Literature Review and Fuzzy Delphi Study.
- **Objective**: This phase identifies key enablers (catalysts) and barriers (impediments) to the implementation of Industry 4.0 in PPC. The Fuzzy Delphi method will validate and refine the factors derived from the literature review, ensuring a combination of theoretical and practical perspectives.

3.4.3 Prioritizing Catalysts and Impediments

- **Method**: MCDM (Fuzzy Best-Worst Method).
- **Objective**: This step involves prioritizing the enablers and barriers identified in the previous step. The Fuzzy Best-Worst Method (BWM) will rank these factors based on expert assessments, providing a clear understanding of their relative importance within the Indian automobile industry.

3.4.4 Analyzing Contextual Relationships Among Catalysts and Impediments

- **Method**: Fuzzy ISM (Interpretive Structural Modeling).
- **Objective**: Fuzzy ISM is used to analyze the relationships between the enablers and barriers identified. This method helps in understanding how these factors

interact with one another, which serve as key drivers, and which are dependent on others for the successful implementation of Industry 4.0 in PPC.

Table 3.1 – Research methodologies selection for objectives

Sr No.	Fuzzy Delphi study
1	The size of a Fuzzy Delphi panel is used by different researcher e.g., Lin, (2013) used 10 experts, Hsu et al., (2010) used 9 experts; Bueno and Salmeron (2008) used 10 experts; Ma et al., (2011) used 13 experts; Bouzon et al., (2016) used 16experts
2	The panel members would be selected from the departments related to Production Planning and control affecting directly or indirectly for the implementation of Industry 4.0 in Production Planning and Control
3	Population- All automobile manufacturers, Sample size- 15-20 Sampling technique- Panel Sampling tool- Questionnaires and Interviews
4	Superior to other similar methodologies like Brainstorming, Nominal group Technique, Multivoting and Electronic Meeting
Sr No.	**Fuzzy CoPras Method**
1	The size of Fuzzy COPRAS and Fuzzy WASPAS Method used by researchers are 18 decision makers used by Dhiman (2020), 12 decision makers used by bekar (2016), 15 decision makers used by Ighravwe (2019) etc
2	Population- All automobile mfg., Sample size- 15, Sampling technique- Panel Sampling, Sampling tool- Questionnaires
3	By MCDM technique the ranking of the Impediments and Catalysts will be calculated which will give the most important element to be focused on while starting the implementation drive of Industry 4.0 in PPC.
4	MCDM has many tools like COPRAS, MOORA, WASPAS, EDAS, CODAS, TOPSIS, VIKOR, CoCoSo in which COPRAS has greater stability and WASPAS being the newest has the greater advantage of power and product

Sr No.	**Fuzzy BWM**
1	The size of expert panel used in various Fuzzy- BWM based scholarly literatures are from 15 to 20. Kumar & A, (2020) used 15 experts, Mahdiyar et al., (2020) used 19 experts in their study.
2	Population- All auto industries, Sample size- 15-20, Sampling technique- Stratified Sampling tool- Questionnaires
3	All the criteria need to be well defined and a questionnaire with 1-9 scale for best and worst ratings need to be prepared for the survey with respect to the surveyor's best and worst choice
4	The Best-Worst Method (BWM) is a vector-based multi-criteria decision-making (MCDM) approach that requires significantly fewer comparisons than matrix-based methods like the Analytic Hierarchy Process (AHP). Specifically, BWM involves only $2n - 3$ comparisons, whereas AHP requires $n(n - 1)/2$ comparisons.
Sr No.	**Fuzzy ISM**
1	Anjali (2016) used 14 panel members, Dewangan (2015) also used 15-20 experts for his ISM study, Bhosale (2016) used 24 expert suggestions, Pramod (2021) used 20 experts for ISM methodology
2	Population- All auto industries, Sample size- 15-20, Sampling technique- Panel Sampling tool- Questionnaires
3	Contextual relationship among the catalysts and among the impediments will be formed based on the variables identified for each cause or problem termed as catalysts and impediments
4	ISM method has the capability of developing a new initial model but do not have capability to validate the model

3.5 *Proposed Methodology & Tools*

Table 3.2 Proposed Methodologies against objectives

S. No.	Research Objectives	Tool Used/ Methodology adopted
A.	To identify and analyze the readiness factors for implementing Industry 4.0 in production planning and control in the automobile industry.	Systematic Literature Review / Fuzzy Delphi Study & Fuzzy COPRAS
B.	To identify the critical catalysts and obstacles for adopting Industry 4.0 in production planning and control in the automobile industry.	Systematic Literature Review / Fuzzy Delphi Study
C.	To prioritize the identified critical catalysts and obstacles for Industry 4.0 implementation in production planning and control in the automobile industry.	MCDM (Fuzzy BWM)
D.	To examine the contextual relationships among the identified catalysts and barriers for Industry 4.0 implementation.	Fuzzy ISM (Interpretive Structural Modelling)

The objectives outlined in Table 3.3 from a comprehensive review of literature conducted in the domain of Production Planning and Control for Industry 4.0 implementation. These objectives will be examined through a systematic literature review to identify relevant readiness factors, followed by analysis using the Fuzzy Delphi and Fuzzy COPRAS methods.

3.6 *Fuzzy Delphi Method*

The Fuzzy Delphi Method (FDM) is an integration of fuzzy set theory with the traditional Delphi technique, originally introduced by Ishikawa in 1993. Noorderhaven (1995) highlighted its effectiveness in addressing the uncertainty or vagueness inherent in group decision-making by relying on expert opinions. FDM assigns different weights to various criteria, enhancing its application in decision-making processes.

The Delphi technique is a structured method for gathering expert opinions, characterized by three core features: anonymous feedback, controlled iterations, and statistical group responses. This technique simplifies the aggregation of group perspectives through repeated surveys, typically conducted twice. By incorporating fuzzy set theory into the Delphi process, FDM offers additional advantages, such as reduced questionnaire time and cost, as noted by Hsu (2010) and Yu-Feng (2008). The use of triangular membership functions in fuzzy theory enables the evaluation of group decisions and the identification of critical factors across different stages.

FDM proves particularly useful when measurable datasets are unavailable. For instance, Aliev (2004) observed that conventional statistical and forecasting methods are ineffective when dealing with intangible evidence, such as subjective opinions on a new product's market potential. In such cases, qualitative forecasting models, which do not rely on historical data, become essential.

Saffie (2016) described FDM as an enhanced and refined version of the classical Delphi method. Unlike the traditional Delphi approach, which is based on mathematical concepts, FDM incorporates probability theory to handle uncertainty in decision-making. By combining fuzzy theory with the conventional Delphi method, FDM accounts for human linguistic preferences and offers a more flexible approach to decision-making.

The classical Delphi method follows a step-by-step process to achieve consensus among a panel of experts. These experts participate in multiple rounds of surveys, where their responses are evaluated and shared with the group after each iteration. This iterative process allows the experts to adjust their responses based on the feedback provided. Ultimately, the final consensus represents the collective judgment of the group. The incorporation of triangular fuzzy sets and fuzzy statistical tools in FDM enhances its ability to model expert opinions and evaluate factors in complex decision-making scenarios.

Delphi study from Past Literature

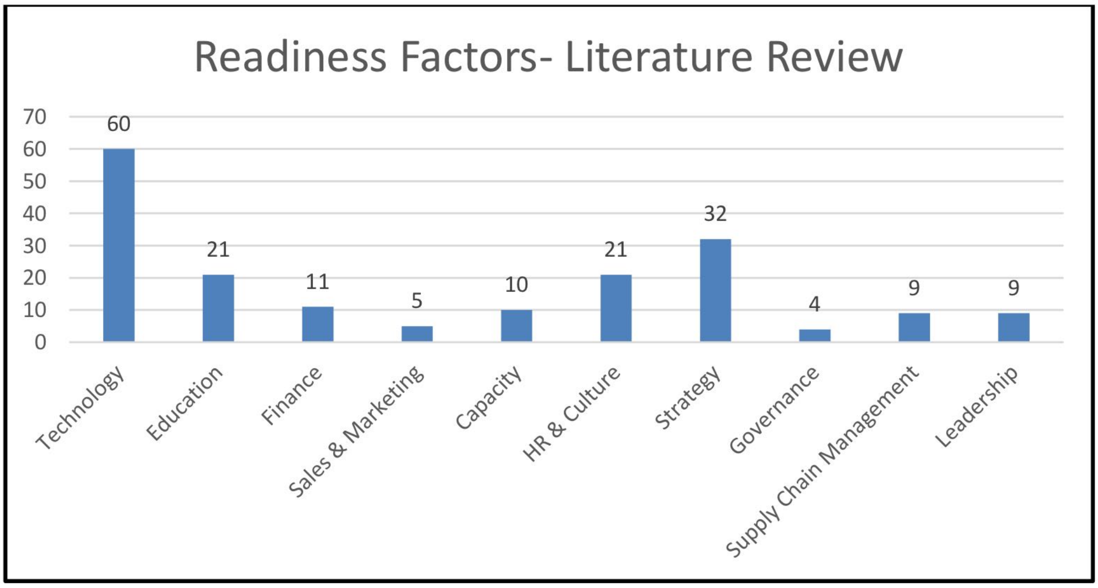
To assess the readiness factors for implementing Industry 4.0 across industries, a substantial amount of data was gathered through an extensive literature review. This study identified numerous readiness factors, which were categorized into parent groups for systematic analysis. These factors were then presented to experts via questionnaires to determine the most relevant readiness factors.

The study by Rahul Kumar Singh, et al. (2024) the readiness factors have been categorized into 10 primary groups:

1. **Technology** – Technological requirements for driving and implementing Industry 4.0 initiatives.
2. **Education** – Skills and knowledge necessary for successful execution.
3. **Finance** – Budget and financial resources required for implementation.
4. **Sales and Marketing** – Insights on benefits, feedback, and feed-forward mechanisms for execution.
5. **Capacity** – Planning and allocation of capacity for seamless execution.
6. **Strategy** – Strategic decision-making for effective planning and implementation.
7. **Leadership** – The role of leadership involvement in driving and executing initiatives.
8. **HR and Culture** – Recruitment and development of talent aligned with Industry 4.0 objectives.
9. **Governance** – Adherence to government policies, regulations, and standards.
10. **Supply Chain Management (SCM)** – The integration of supply chain activities in driving and implementing Industry 4.0 strategies.

There we around 182 different readiness factors which were derived for the Fuzzy Delphi Study which are as follows.

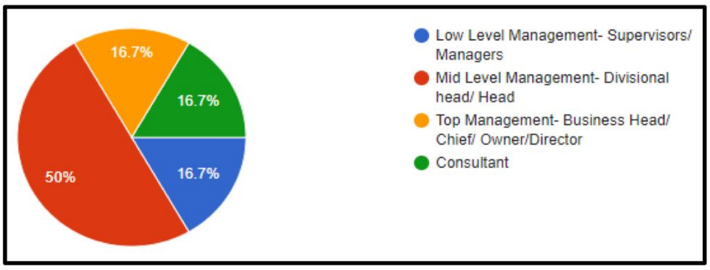
Figure 3.1 Readiness Factors from Literature Review



Source: Singh et al. (2024)

An extensive literature review identified approximately 182 readiness factors, which were classified into ten broad categories referred to as parent groups (Figure 01). Each of these factors plays a role at various stages of implementing Industry 4.0 across industries. The questionnaire was designed to gather inputs from experts at different management levels, as illustrated in Figure 3.2.

Figure 3.2 Levels of management involved



Source: Singh et al. (2024)

In the first round of the study, 50% of the participating experts were from middle management, while the remaining experts were evenly distributed across top management, lower management, and consultants, each constituting 16.7% of the total participants.

Fuzzy Delphi Calculation

Table 3.3 Fuzzy Set for Delphi Study

Variable	**Rating scale**	**Fuzzy Scale**
Strongly disagree	1	(0.0, 0.1, 0.2)
Disagree	2	(0.1, 0.2, 0.4)
Not Sure	3	(0.2, 0.4, 0.6)
Agree	4	(0.4, 0.6, 0.8)
Strongly Agree	5	(0.6, 0.8, 1.0)

The fuzzy set shown in Table 02 is developed from the Fuzzy Triangular Number Matrix, where a 1 to 5 rating scale represents levels of agreement. The scale ranges from "Strongly Disagree" to "Strongly Agree," with corresponding triangular fuzzy numbers assigned as follows:

- **Strongly Disagree**: (0.0, 0.1, 0.2)
- **Disagree**: (0.1, 0.2, 0.4)
- **Neutral/Not Sure**: (0.2, 0.4, 0.6)
- **Agree**: (0.4, 0.6, 0.8)
- **Strongly Agree**: (0.6, 0.8, 1.0)

These fuzzy sets replace the conventional rating scale and are used for subsequent fuzzy calculations.

Data analysis is conducted using the Fuzzy Delphi Method and the Fuzzy Triangular Matrix. To determine the level of agreement among experts, the threshold value (d) between two fuzzy numbers m=(m1,m2,m3)m = (m_1, m_2, m_3)m=(m1,m2,m3) and n=(n1,n2,n3)n = (n_1, n_2, n_3)n=(n1,n2,n3) is calculated using the formula:

d=13[(m1−n1)2+(m2−n2)2+(m3−n3)2](1)d = \sqrt{\frac{1}{3} \left[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2 \right]} \tag{1}d=31[(m1−n1)2+(m2−n2)2+(m3−n3)2] (1)

Step 1: Construct a Likert scale table using the responses from 18 experts, who evaluated 182 potential readiness factors on a 1–5 scale.

Table3.4 Likert scale

EXPERT	LIKERT SCALE																
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**…**	**….**	**177**	**178**	**179**	**180**	**181**	**182**
1	5	2	5	3	1	4	3	3	4	--	--	2	2	2	4	5	4
2	2	5	2	5	5	5	5	5	5	--	--	5	3	4	5	4	4
3	3	1	1	1	2	2	2	3	3	--	--	2	3	3	3	3	2
4	1	2	1	1	2	3	2	3	2	--	--	5	3	2	3	2	2
5	5	3	2	3	5	2	4	3	2	--	--	5	2	2	2	2	3
6	4	1	5	2	5	5	1	3	5	--	--	5	2	5	2	1	2
7	2	2	3	1	5	2	2	3	4	--	--	2	2	2	4	1	3
8	3	2	1	2	5	3	5	5	5	--	--	3	5	5	2	2	2
9	5	4	2	1	5	2	4	4	5	--	--	3	3	3	4	2	4
10	4	3	3	2	5	5	1	1	5	--	--	2	5	2	2	3	2
11	1	2	2	2	1	2	2	2	5	--	--	4	2	2	4	5	4
12	3	1	4	2	5	3	5	3	5	--	--	2	5	2	2	2	2
13	5	2	5	2	5	2	4	5	5	--	--	5	2	4	5	4	2
14	2	5	3	2	4	5	1	4	3	--	--	1	5	5	2	5	2
15	4	4	2	2	5	3	2	2	5	--	--	2	4	2	4	2	2
16	4	2	4	3	2	2	4	3	3	--	--	3	2	3	2	3	4
17	4	2	4	4	1	1	4	4	2	--	--	4	1	4	5	4	5
18	4	3	5	5	4	5	5	5	3	--	--	5	2	5	1	5	5

Table 3.4 illustrates the Likert scale used for the Fuzzy Delphi process, where 18 decision-makers provided their inputs on 182 readiness factors. These inputs were

recorded in a tabular format and rated using the scale defined in Table 02. The scale assigns values as follows:

- **Strongly Disagree**: 1
- **Disagree**: 2
- **Not Sure**: 3
- **Agree**: 4
- **Strongly Agree**: 5

Step 2: Develop a Triangular Fuzzy Scale Matrix based on the ratings provided by the experts.

Table 3.5 Triangular Fuzzy scale matrix

EXPERT	FUZZY SCALE														
	1			**2**			**----**			**181**			**182**		
1	0.6	0.8	1	0	0.8	0.4				0.2	0.4	0.6	0	0	0.2
2	0	0.2	0.4	0.6	0.8	1				0.6	0.8	1	0.6	0.8	1
3	0.2	0.4	0.6	0	0	0.2				0	0	0.2	0	0.2	0.4
4	0	0	0.2	0	0.2	0.4				0	0	0.2	0	0.2	0.4
5	0.6	0.8	1	0.2	0.4	0.6				0.2	0.4	0.6	0.6	0.8	1
6	0.4	0.6	0.8	0	0	0.2				0	0.2	0.4	0.6	0.8	1
7	0	0.2	0.4	0	0.2	0.4				0	0	0.2	0.6	0.8	1
8	0.2	0.4	0.6	0	0.2	0.4				0	0.2	0.4	0.6	0.8	1
9	0.6	0.8	1	0.4	0.6	0.8				0	0	0.2	0.6	0.8	1
10	0.4	0.6	0.8	0.2	0.4	0.6				0	0.2	0.4	0.6	0.8	1
11	0	0	0.2	0	0.2	0.4				0	0.2	0.4	0	0	0.2
12	0.2	0.4	0.6	0	0	0.2				0	0.2	0.4	0.6	0.8	1

13	0.6	0.8	1	0	0.2	0.4				0	0.2	0.4	0.6	0.8	1
14	0	0.2	0.4	0.6	0.8	1				0	0.2	0.4	0.4	0.6	0.8
15	0.4	0.6	0.8	0.4	0.6	0.8				0	0.2	0.4	0.6	0.8	1
16	0.4	0.6	0.8	0	0.2	0.4				0.2	0.4	0.6	0	0.2	0.4
17	0.4	0.6	0.8	0	0.2	0.4				0.4	0.6	0.8	0	0	0.2
18	0.4	0.6	0.8	0.2	0.4	0.6				0.6	0.8	1	0.4	0.6	0.8
AVERAGE	**0.300**	**0.478**	**0.678**	**0.144**	**0.344**	**0.511**				**0.122**	**0.278**	**0.478**	**0.378**	**0.544**	**0.744**
	m1	**m2**	**m3**	**m1**	**m2**	**m3**	**m1**	**m2**	**m3**	**m1**	**m2**	**m3**	**m1**	**m2**	**m3**

Table 3.5 presents the derived Triangular Fuzzy Scale, where the inputs from 18 decision-makers for each of the 182 readiness factors are structured based on the fuzzy sets defined in Table 3.5. The fuzzy sets are represented as follows:

- **Strongly Disagree**: (0.0, 0.1, 0.2)
- **Disagree**: (0.1, 0.2, 0.4)
- **Neutral/Not Sure**: (0.2, 0.4, 0.6)
- **Agree**: (0.4, 0.6, 0.8)
- **Strongly Agree**: (0.6, 0.8, 1.0)

These fuzzy sets replace the conventional rating scale for further calculations. The average of each column is computed and represented as m1m_1m1, m2m_2m2, and m3m_3m3 for each readiness factor based on the decisions provided by the 18 decision-makers.

Step 3- Finding out the threshold "d" value

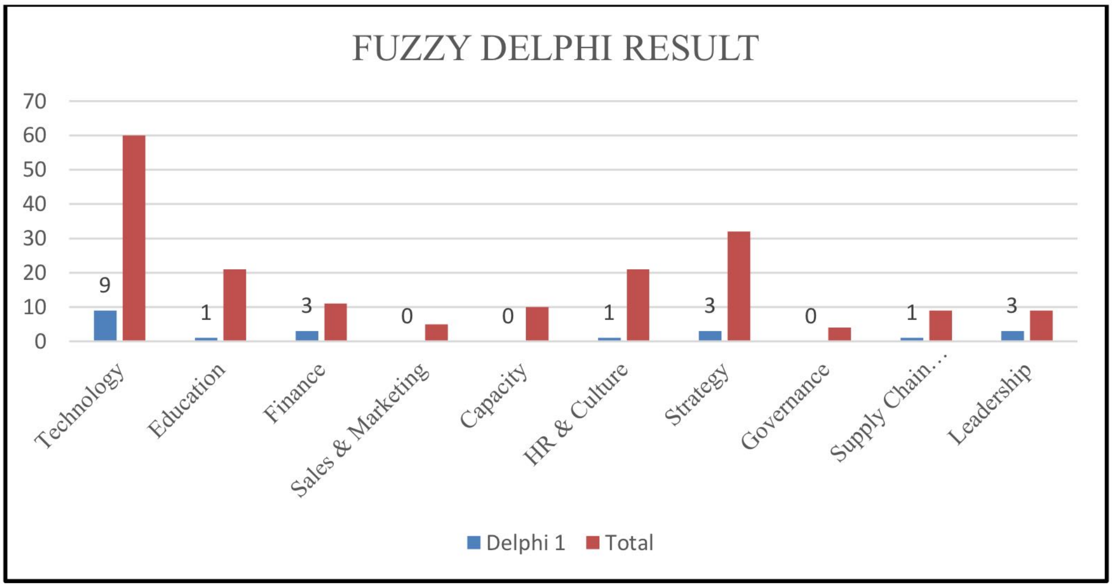
Table 3.6 Threshold matrix

EXPERT	ITEM								
	1	**2**	**3**	**-----**	**-----**	**179**	**180**	**181**	**182**
1	0.5	0.5	0.4			0.3	0.0	0.1	0.0
2	0.4	0.7	0.5			0.6	0.6	0.5	0.3
3	0.1	0.5	0.4			0.3	0.3	0.1	0.3
4	0.7	0.2	0.5			0.0	0.3	0.1	0.6
5	0.5	0.1	0.5			0.3	0.3	0.1	0.6
6	0.2	0.5	0.5			0.6	0.6	0.1	0.3
7	0.4	0.2	0.4			0.3	0.3	0.1	0.0
8	0.1	0.2	0.1			0.0	0.6	0.5	0.3
9	0.5	0.4	0.1			0.3	0.3	0.2	0.3
10	0.2	0.1	0.4			0.6	0.6	0.7	0.3
11	0.7	0.2	0.2			0.3	0.3	0.4	0.3
12	0.1	0.5	0.4			0.0	0.6	0.1	0.3
13	0.5	0.2	0.5			0.3	0.3	0.5	0.3
14	0.4	0.7	0.7			0.6	0.6	0.2	0.3
15	0.2	0.4	0.4			0.0	0.3	0.4	0.3
16	0.2	0.2	0.1			0.3	0.3	0.1	0.3
17	0.2	0.2	0.2			0.6	0.3	0.2	0.6
18	0.2	0.1	0.5			0.6	0.6	0.5	0.3
Value of d each item	0.339	0.327	0.383			0.350	0.402	0.280	0.326
Value of d construct	**0.313**								

Table 3.6 provides the calculated threshold value d for each of the 182 readiness factors, with an average value of 0.313, as identified through an extensive literature review. By applying the criteria d≤0.2d \leq 0.2d≤0.2 and ensuring at least 75% expert group consensus, 21 readiness factors were identified as the most probable for implementing Industry 4.0 in Production Planning and Control.

The threshold values were determined through the defuzzification of the fuzzy matrix using the threshold formula. The average of each column was then calculated to establish the threshold for each readiness factor and assess them based on group consensus.

Figure 3.3 Fuzzy Delphi result



Source: author's own work

The results of the Fuzzy Delphi study revealed that the 18 experts indicated that readiness factors related to sales and marketing, capacity, and governance hold minimal or no significance for the implementation of Industry 4.0 in Production Planning and Control. Following the completion of the Fuzzy Delphi process, the initial 182 readiness factors were narrowed down to 21, which were identified as the most significant. These finalized factors are presented in Figure 3.3.

These are the most preferable readiness factors which got identified after Fuzzy Delphi study

Table 3.7 Readiness factors after Fuzzy Delphi study

1	Requirement of Industrial Internet of Things (IIoT) in Industry for implementation of INDUSTRY 4.0 in PPC
2	Level of digitization of the organization for implementation of INDUSTRY 4.0 in PPC
3	Digital Capabilities of the industry for implementation of INDUSTRY 4.0 in PPC

4	Capacity of Data Storage of the industry for implementation of INDUSTRY 4.0 in PPC
5	Machine communication- Hardware component for implementation of INDUSTRY 4.0 in PPC
6	Requirement of Data Driven services in industry for implementation of INDUSTRY 4.0 in PPC
7	Requirement of IOT platforms for implementation of INDUSTRY 4.0 in PPC
8	Availability of Internet and Communication Technology in industry for implementation of INDUSTRY 4.0 in PPC
9	Availability of IT Integration software for implementation of INDUSTRY 4.0 in PPC
10	Requirement of Knowledge about technology in industry for implementation of INDUSTRY 4.0 in PPC
11	Requirement of Calculating the Cost of technology for implementation of Industry 4.0 in PPC
12	Requirement of calculating the Implementation cost for implementation of Industry 4.0 in PPC
13	Requirement of Financial aid given for implementation of Industry 4.0 in PPC
14	Requirement of technology Proficiency in industry for implementation of Industry 4.0 in PPC
15	Availability of Leadership in industry for implementation of Industry 4.0 in PPC
16	Presence of long-term strategy in industry for implementation of Industry 4.0 in PPC
17	Requirement of Road map Strategy in industry for implementation of Industry 4.0 in PPC
18	Evaluation of digitization of supply chain in industry for implementation of Industry 4.0 in PPC
19	Requirement of Top management involvement and commitment in industry for implementation of Industry 4.0 in PPC
20	Requirement of Collaboration Network in industry for implementation of Industry 4.0 in PPC

21	Presence of change management in industry for implementation of Industry 4.0 in PPC

Table 3.7 presents the list of 21 most likely readiness factors, selected from the initial 182 factors identified through an extensive literature review and analysed using the Fuzzy Delphi method. These 21 factors are considered critical and essential for the successful implementation of Industry 4.0 in Production Planning and Control. They serve as foundational elements for future production planning, where digitization will play a pivotal role.

3.7 Fuzzy CoPrAs Method

The Complex Proportional Assessment (COPRAS) method, developed by Zavadskas et al. (1994), provides a step-by-step approach for ranking and evaluating alternatives based on their significance and utility. COPRAS is a multi-criteria decision-making (MCDM) technique that integrates fuzzy set theory with proportional assessment to enhance decision-making accuracy. This method allows for a comparative evaluation of alternatives to determine their relative performance.

Given the need for fuzzy-based MCDM techniques to address redundancies and ambiguities in data, this study adopts the COPRAS model with fuzzy datasets to achieve more reliable and precise outcomes.

Fuzzy set for Calculation of CoPrAs method

For this study we have to consider Triangular Fuzzy Number. A fuzzy number ã on R is termed as a TFNs if its $\mu_{\tilde{a}}(x)$: R–› [0,1] membership function equal to

$$\mu_{\tilde{a}}(x) = \begin{cases} 0, & x < l \\ \frac{x-l}{m-l}, & l \le x \le m \\ \frac{u-x}{u-m}, & m \le x \le u \\ 0, & x > u \end{cases} \quad \ldots\ldots (1)$$

Where *l, m* and *u* are unfolds the lower, modal and upper values respectively of the support of ã, All are crisp numbers ($- \infty < l \leq m \leq u < +\infty$) A Triangular Fuzzy Numbers can be shown as a triplet *(l,m,u)* triangular

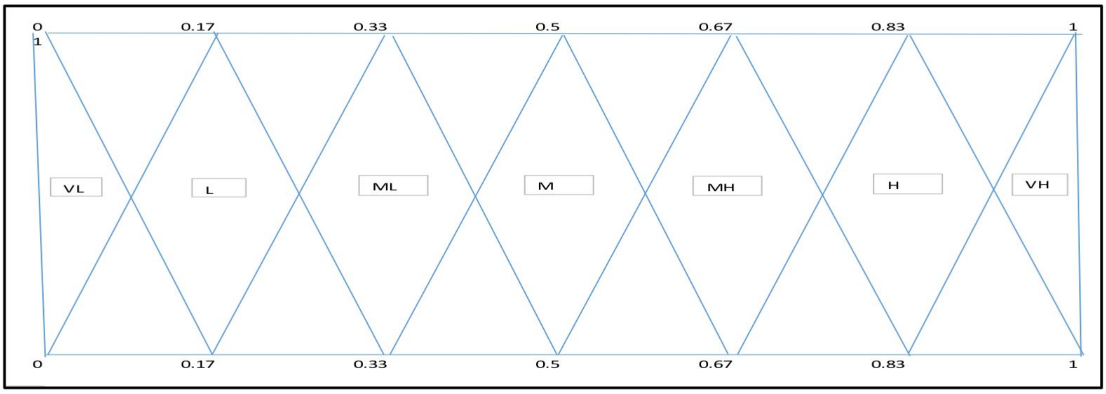
Step-1: Linguistic variables below and their corresponding TFNs below in table for assessing the readiness factors based on parameter

Table3.8 Linguistic variables-1

ABB	MEANING	MAGNITUDE	MAGNITUDE	MAGNITUDE
VH	VERY HIGH	0.83	1	1
H	HIGH	0.67	0.83	1
MH	MEDIUM HIGH	0.5	0.67	0.83
M	MEDIUM	0.33	0.5	0.67
ML	MEDIUM LOW	0.17	0.33	0.5
L	LOW	0	0.17	0.33
VL	VERY LOW	0	0	0.17

The above Fuzzy set in Table 3.8 is the linguistic variables derived from the Fuzzy Triangular Number Matrix in which rating scale from VL to VH describes from Very Low to Very High with three vertices as Very Low with 0.0, 0.0 & 0.17 Low with 0.0, 0.17 & 0.33 Medium Low with 0.17, 0.33 & 0.5, Medium stands for 0.17, 0.33 & 0.5 and medium high means 0.5, 0.67 & 0.83, High stands for 0.67, 0.83 & 1 and Very high stands for 0.83, 1.0 & 1.0. These Fuzzy sets will replace the rating scale for further Fuzzy CoPrAs Method calculation for ranking among the most probable readiness factors which was identified by Fuzzy Delphi study

Figure 3.4 Triangular Fuzzy set-1



These linguistic variables are divided into 7 groups as mentioned in Figure 04 in which each group denotes a unique set of Triangular Fuzzy numbers which will be used for the calculation in Fuzzy Copras method for identifying the most appropriate readiness factors for implementation of Industry 4.0 in Production Planning and Control.

Linguistic variables and their corresponding TFNs for assessing the weights based on parameters.

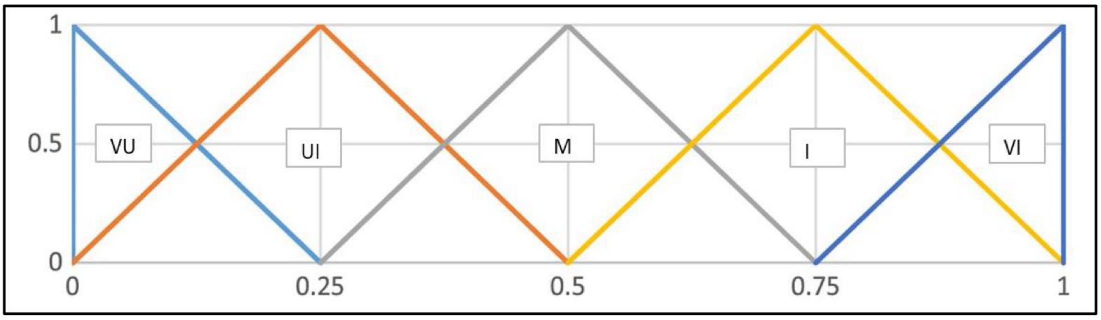
Table 3.9 Linguistic variables-2

ABB	MEANING	MAGNITUDE	MAGNITUDE	MAGNITUDE
VI	Very Important (VI)	0.75	1	1
I	Important(I)	0.5	0.75	1
M	Medium(M)	0.25	0.5	0.75
UI	Unimportant(U)	0	0.25	0.5
VU	Very Unimportant (VU)	0	0	0.25

The above Fuzzy set in Table 3.9 is the linguistic variables derived from the Fuzzy Triangular Number Matrix in which rating scale from VI to VU describes from Very Unimportant(VU) to Very Important with three vertices as Very Unimportant with 0.0, 0.0 & 0.25 Unimportant with 0.0, 0.25 & 0.5 Medium Important with 0.2, 0.5 & 0.75, Important stands for 0.5, 0.75 & 1.0 and Very Important means 0.75, 1.0 & 1.0. These

Fuzzy sets will replace the rating scale for further Fuzzy CoPrAs calculation for finding out the parameters to rate the 21 most probable readiness factors.

Figure 3.5 Triangular Fuzzy set-2



These linguistic variables are divided into 5 groups as mentioned in Figure 05 in which each group denotes a unique set of Triangular Fuzzy numbers which will be used for the calculation in Fuzzy Copras method for identifying the most appropriate readiness factors for implementation of Industry 4.0 in Production Planning and Control.
Fuzzy Complex Proportional Assessment method has to have a fuzzy set of linguistic variables for evaluating the most appropriate readiness factors and for constructing the weights.

The assessment includes the survey of five senior leadership of different automobile industries in India which helped this study for construction of Decision matrix and Weighted Matrix.

Construction of Decision Matrix

$$D = \begin{bmatrix} x11 & \cdots & x1n \\ \vdots & \ddots & \vdots \\ xm1 & \cdots & xmn \end{bmatrix} \quad \ldots\ldots\ldots\ldots (2)$$

$W_j = [W_1 \ldots\ldots W_n]$, where $\sum_{j=1}^{n}(W1 \ldots \ldots . Wn) = 1$

Before construction of Decision Matrix, few leading and lagging indicators were derived to measure the most appropriate readiness factors among 21 shortlisted readiness factors from Delphi study.

These leading and lagging indicators are:

1. **Capability** – Capability means how much capable is the readiness factors for implementation of Industry 4.0 in Production Planning and Control.
2. **Stability** – Stability means even after many times the readiness factors gives the same result for implementation of Industry 4.0 in Production Planning and Control.
3. **Networking** – Networking refers to the connectivity between the hardware available for implementation of Industry 4.0 in Production Planning and Control
4. **Information Technology advantage** – IT means the flow of data in the digital format inside and outside the shop for implementation of Industry 4.0 in Production Planning and Control
5. **Extent of auto correct** – This means that the devices connected, and performance of the devices or technologies should be in such a way that it will either give alarm or self-align itself towards the mean to give better result for implementation of Industry 4.0 in Production Planning and Control
6. **Ease of collaboration with new devices** – Collaboration of the devices means the compatibility of the hardware and software to feed the agile environment for implementation of Industry 4.0 in Production Planning and Control
7. **Decision making** – The readiness factors identified should be able to decide the preferences and sequence of its usage and maintenance for implementation of Industry 4.0 in Production Planning and Control
8. **Extent of Data Exchange** – This refers to the transfer of the digital data limit to which the exchange can happen smoothly for implementation of Industry 4.0 in Production Planning and Control
9. **Extent of forecasting** – This refers to the forecasting and predicting the future hazards or opportunity's ability for implementation of Industry 4.0 in Production Planning and Control
10. **Extent of up gradation** – Up gradation is always required in this agile environment; the readiness factors should be capable of getting upgraded frequently and should not have any technology which could not be updated or

upgraded for implementation of Industry 4.0 in Production Planning and Control

11. **Cost involved** – For every business, cost is the major contributor. The less the cost the more is the chances of any new ideas implemented.
12. **Time for implementation** – Now in agile environment, adaptive nature of the readiness factors should not take much time. Time required should be minimum with high result for implementation of Industry 4.0 in Production Planning and Control.

Each parameter are presented as a survey to 5 different senior leadership of top automobile industries in India for their views on rating the parameters with respect to readiness factors which was derived from Delphi study among the given linguistic variables. There after super imposing the Fuzzy sets as per the Triangular Fuzzy Number relative to the linguistic variables. The final matrix is prepared by the Fuzzy Aggregation Technique for each of the parameters shown below.

Decision Matrix

Table3.10 Decision Matrix for Fuzzy CoPrAs

Readiness Factors	Capability			Stability			Networking			Information Technology advantage			Extent of auto correct			Ease of collaboration with new devices			Decision making			Extent of Data Exchange			Extent of forecasting			Extend of up gradation			Cost involved			Time for implementation		
Requirement of Industrial Internet of Things (IIoT)	0.70	0.87	0.97	0.70	0.87	0.97	0.67	0.83	0.97	0.67	0.83	0.93	0.00	0.07	0.23	0.77	0.93	1.00	0.00	0.07	0.23	0.77	0.93	1.00	0.00	0.14	0.30	0.80	0.97	1.00	0.33	0.50	0.67	0.03	0.10	0.27
Level of digitization	0.10	0.23	0.40	0.10	0.23	0.40	0.63	0.80	0.93	0.80	0.97	1.00	0.30	0.43	0.60	0.80	0.97	1.00	0.77	0.93	1.00	0.77	0.93	1.00	0.53	0.70	0.86	0.80	0.97	1.00	0.77	0.93	1.00	0.73	0.90	0.97
Digital Capabilities	0.73	0.90	0.97	0.73	0.90	0.97	0.67	0.83	0.93	0.66	0.83	0.90	0.70	0.87	0.93	0.73	0.90	0.97	0.77	0.93	1.00	0.80	0.97	1.00	0.80	0.97	1.00	0.80	0.97	1.00	0.70	0.87	0.97	0.77	0.93	1.00
Capacity of Data Storage	0.76	0.93	0.97	0.76	0.93	0.97	0.10	0.20	0.37	0.43	0.60	0.77	0.23	0.40	0.57	0.73	0.90	0.93	0.30	0.47	0.63	0.77	0.93	1.00	0.00	0.03	0.20	0.77	0.93	1.00	0.70	0.87	0.93	0.00	0.10	0.27
Machine communication- Hardware component	0.76	0.93	0.97	0.76	0.93	0.97	0.77	0.93	1.00	0.70	0.87	0.93	0.27	0.43	0.60	0.63	0.80	0.90	0.00	0.03	0.20	0.80	0.97	1.00	0.00	0.03	0.20	0.73	0.90	1.00	0.60	0.77	0.93	0.00	0.10	0.27
Requirement of Data Driven services	0.73	0.90	0.97	0.73	0.90	0.97	0.60	0.76	0.90	0.80	0.97	1.00	0.77	0.93	1.00	0.76	0.93	0.97	0.76	0.93	0.97	0.73	0.90	1.00	0.80	0.97	1.00	0.80	0.97	1.00	0.73	0.90	1.00	0.80	0.97	1.00
Requirement of IOT platforms	0.83	1.00	1.00	0.83	1.00	1.00	0.70	0.87	0.93	0.53	0.70	0.87	0.00	0.07	0.23	0.70	0.87	0.93	0.80	0.97	1.00	0.40	0.57	0.74	0.40	0.57	0.74	0.77	0.93	1.00	0.77	0.93	1.00	0.77	0.93	1.00
Availability of Internet and Communication Technology	0.67	0.83	0.97	0.67	0.83	0.97	0.57	0.73	0.90	0.77	0.93	1.00	0.77	0.93	1.00	0.76	0.93	0.97	0.77	0.93	1.00	0.80	0.97	1.00	0.80	0.97	1.00	0.80	0.97	1.00	0.77	0.93	1.00	0.77	0.93	1.00

Availability of IT Integration software	0.73	0.90	0.97	0.73	0.90	0.97	0.60	0.77	0.90	0.80	0.97	1.00	0.77	0.93	1.00	0.77	0.93	1.00
Requirement of Knowledge about technology	0.36	0.53	0.70	0.36	0.53	0.70	0.07	0.17	0.33	0.57	0.73	0.90	0.13	0.17	0.34	0.00	0.07	0.23
Requirement of Calculating the Cost of technology	0.80	0.97	1.00	0.80	0.97	1.00	0.03	0.07	0.24	0.13	0.20	0.37	0.00	0.03	0.20	0.00	0.03	0.20
Requirement of calculating the Implementation cost	0.77	0.93	1.00	0.77	0.93	1.00	0.00	0.10	0.27	0.00	0.03	0.20	0.00	0.03	0.20	0.00	0.03	0.20
Requirement of Financial aid	0.70	0.87	0.97	0.70	0.87	0.97	0.03	0.10	0.27	0.10	0.13	0.30	0.00	0.03	0.20	0.00	0.03	0.20
Requirement of technology Proficiency	0.33	0.50	0.67	0.40	0.57	0.74	0.03	0.13	0.30	0.60	0.77	0.93	0.00	0.03	0.20	0.00	0.07	0.23
Availability of Leadership	0.70	0.87	0.97	0.70	0.87	0.97	0.03	0.07	0.24	0.10	0.13	0.30	0.80	0.97	1.00	0.80	0.97	1.00
Presence of long-term strategy	0.63	0.80	0.93	0.63	0.80	0.93	0.07	0.13	0.30	0.10	0.13	0.30	0.80	0.97	1.00	0.67	0.83	0.93
Requirement of Road map Strategy	0.83	1.00	1.00	0.83	1.00	1.00	0.07	0.13	0.30	0.13	0.20	0.37	0.80	0.97	1.00	0.66	0.83	0.90

Availability of IT Integration software	0.80	0.97	1.00	0.77	0.93	1.00	0.80	0.97	1.00	0.70	0.87	0.97	0.77	0.93	1.00	0.30	0.47	0.64
Requirement of Knowledge about technology	0.73	0.90	0.97	0.77	0.93	1.00	0.80	0.97	1.00	0.70	0.86	1.00	0.00	0.07	0.23	0.73	0.90	1.00
Requirement of Calculating the Cost of technology	0.00	0.07	0.23	0.17	0.25	0.42	0.80	0.97	1.00	0.70	0.87	0.97	0.33	0.50	0.67	0.77	0.93	1.00
Requirement of calculating the Implementation cost	0.00	0.03	0.20	0.07	0.10	0.27	0.77	0.93	1.00	0.70	0.87	0.93	0.36	0.53	0.70	0.77	0.93	1.00
Requirement of Financial aid	0.00	0.00	0.17	0.13	0.20	0.37	0.80	0.97	1.00	0.83	1.00	1.00	0.30	0.47	0.64	0.80	0.97	1.00
Requirement of technology Proficiency	0.80	0.97	1.00	0.77	0.93	1.00	0.80	0.97	1.00	0.67	0.83	0.97	0.00	0.03	0.20	0.73	0.90	1.00
Availability of Leadership	0.80	0.97	1.00	0.47	0.63	0.80	0.80	0.97	1.00	0.73	0.90	0.97	0.40	0.57	0.73	0.80	0.97	1.00
Presence of long-term strategy	0.80	0.97	1.00	0.37	0.53	0.70	0.77	0.93	1.00	0.70	0.87	0.93	0.36	0.53	0.70	0.77	0.93	1.00
Requirement of Road map Strategy	0.80	0.97	1.00	0.27	0.43	0.60	0.80	0.97	1.00	0.77	0.93	1.00	0.37	0.53	0.70	0.77	0.93	1.00

Evaluation of digitization of supply chain	0.63	0.80	0.93	0.63	0.80	0.93	0.70	0.87	0.97	0.83	1.00	1.00	0.64	0.80	0.97	0.77	0.93	1.00	0.80	0.97	1.00	0.80	0.97	1.00	0.80	0.97	1.00	0.77	0.93	1.00	0.00	0.03	0.20	0.73	0.90	0.97
Requirement of Top management involvement and commitment	0.60	0.77	0.90	0.60	0.77	0.90	0.13	0.27	0.43	0.17	0.23	0.40	0.70	0.87	0.93	0.80	0.97	1.00	0.77	0.93	1.00	0.27	0.43	0.60	0.80	0.97	1.00	0.70	0.87	0.93	0.40	0.57	0.73	0.73	0.90	0.97
Requirement of Collaboration Network	0.73	0.90	1.00	0.73	0.90	1.00	0.60	0.77	0.93	0.73	0.90	0.97	0.73	0.90	0.97	0.70	0.87	0.93	0.73	0.90	1.00	0.67	0.83	0.90	0.73	0.90	1.00	0.80	0.97	1.00	0.73	0.90	1.00	0.33	0.50	0.67
Presence of change management	0.13	0.30	0.47	0.13	0.30	0.47	0.76	0.93	0.97	0.67	0.83	0.93	0.77	0.93	1.00	0.70	0.87	0.97	0.80	0.97	1.00	0.77	0.93	1.00	0.77	0.93	1.00	0.77	0.93	1.00	0.77	0.93	1.00	0.80	0.97	1.00

The Table3.10 represents the decision matrix based on the decision maker's responses where the decision makers have made some leading and lagging parameters from which we can rate the readiness factors against. The ratings are then converted into Fuzzy sets as mentioned in table 7 and the average of 5 decision makers for that particular readiness factors. The above table consists of average value of 5 decision makers and then plotted on against each cell for calculation in decision matrix.

Normalized Matrix

$$n_{ij} = \frac{x\,ij}{\sum_{j=1}^{n} xij} \quad \text{……….(3)}$$

Table 3.11 Normalized Matrix for Fuzzy CoPrAs

Readiness Factors	Capability			Stability			Networking			Information Technology advantage			Extent of auto correct			Ease of collaboration with new devices			Decision making			Extent of Data Exchange			Extent of forecasting			Extend of up gradation			Cost involved			Time for implementation		
Requirement of Industrial Internet of Things (IIoT)	0.05	0.05	0.05	0.05	0.05	0.05	0.09	0.08	0.07	0.06	0.06	0.06	0.00	0.01	0.02	0.07	0.06	0.06	0.00	0.00	0.01	0.06	0.06	0.06	0.00	0.01	0.02	0.05	0.05	0.05	0.03	0.04	0.04	0.00	0.01	0.01
Level of digitization	0.01	0.01	0.02	0.01	0.01	0.02	0.08	0.08	0.07	0.08	0.07	0.07	0.03	0.04	0.04	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.04	0.04	0.05	0.05	0.05	0.05	0.08	0.07	0.06	0.06	0.06	0.05
Digital Capabilities	0.06	0.05	0.05	0.05	0.05	0.05	0.08	0.08	0.07	0.06	0.06	0.06	0.08	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.07	0.07	0.06	0.06	0.06	0.06
Capacity of Data Storage	0.06	0.06	0.05	0.06	0.06	0.05	0.01	0.02	0.03	0.04	0.05	0.05	0.03	0.03	0.04	0.06	0.06	0.06	0.02	0.03	0.04	0.06	0.06	0.06	0.00	0.00	0.01	0.05	0.05	0.05	0.07	0.07	0.06	0.00	0.01	0.01
Machine communication- Hardware component	0.06	0.06	0.05	0.06	0.06	0.05	0.10	0.09	0.07	0.07	0.07	0.06	0.03	0.04	0.04	0.05	0.05	0.05	0.00	0.00	0.01	0.07	0.06	0.06	0.00	0.00	0.01	0.05	0.05	0.05	0.06	0.06	0.06	0.00	0.01	0.01
Requirement of Data Driven services	0.06	0.05	0.05	0.05	0.05	0.05	0.08	0.07	0.07	0.08	0.07	0.07	0.08	0.08	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.07	0.07	0.06	0.06	0.06	0.06
Requirement of IOT platforms	0.06	0.06	0.05	0.06	0.06	0.05	0.09	0.08	0.07	0.05	0.05	0.06	0.00	0.01	0.02	0.06	0.06	0.06	0.07	0.07	0.06	0.03	0.04	0.04	0.03	0.03	0.04	0.05	0.05	0.05	0.08	0.07	0.06	0.06	0.06	0.06
Availability of Internet and	0.05	0.05	0.05	0.05	0.05	0.05	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.08	0.07	0.06	0.06	0.06	0.06

Communication Technology																																				
Availability of IT Integration software	0.06	0.05	0.05	0.05	0.05	0.05	0.08	0.07	0.07	0.08	0.07	0.07	0.08	0.08	0.07	0.07	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.04	0.04	0.05	0.08	0.07	0.06	0.02	0.03	0.04
Requirement of Knowledge about technology	0.03	0.03	0.04	0.03	0.03	0.04	0.01	0.02	0.02	0.06	0.06	0.06	0.01	0.01	0.02	0.00	0.00	0.01	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.04	0.04	0.05	0.00	0.01	0.01	0.06	0.06	0.06
Requirement of Calculating the Cost of technology	0.06	0.06	0.05	0.06	0.06	0.05	0.00	0.01	0.02	0.01	0.02	0.02	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.02	0.02	0.06	0.06	0.05	0.04	0.04	0.05	0.03	0.04	0.04	0.06	0.06	0.06
Requirement of calculating the Implementation cost	0.06	0.06	0.05	0.06	0.06	0.05	0.00	0.01	0.02	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.02	0.06	0.06	0.05	0.04	0.05	0.05	0.04	0.04	0.04	0.06	0.06	0.06
Requirement of Financial aid	0.05	0.05	0.05	0.05	0.05	0.05	0.00	0.01	0.02	0.01	0.01	0.02	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.02	0.06	0.06	0.05	0.05	0.05	0.05	0.03	0.04	0.04	0.06	0.06	0.06
Requirement of technology Proficiency	0.02	0.03	0.04	0.03	0.03	0.04	0.00	0.01	0.02	0.06	0.06	0.06	0.00	0.00	0.01	0.00	0.00	0.01	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.04	0.04	0.05	0.00	0.00	0.01	0.06	0.06	0.06
Availability of Leadership	0.05	0.05	0.05	0.05	0.05	0.05	0.00	0.01	0.02	0.01	0.01	0.02	0.09	0.08	0.07	0.07	0.07	0.06	0.07	0.07	0.06	0.04	0.04	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.06	0.06	0.06
Presence of long-term strategy	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.02	0.01	0.01	0.02	0.09	0.08	0.07	0.06	0.06	0.06	0.07	0.07	0.06	0.03	0.03	0.04	0.06	0.06	0.05	0.04	0.05	0.05	0.04	0.04	0.04	0.06	0.06	0.06

Requirement of Road map Strategy	0.06	0.06	0.05	0.06	0.06	0.05	0.01	0.01	0.02	0.01	0.02	0.02	0.09	0.08	0.07	0.06	0.06	0.05	0.07	0.07	0.06	0.02	0.03	0.03	0.06	0.06	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.06	0.06	0.06
Evaluation of digitization of supply chain	0.05	0.05	0.05	0.05	0.05	0.05	0.09	0.08	0.07	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.07	0.07	0.06	0.07	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.00	0.00	0.01	0.06	0.06	0.05
Requirement of Top management involvement and commitment	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.03	0.03	0.02	0.02	0.03	0.08	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.02	0.03	0.03	0.06	0.06	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.06	0.06	0.05
Requirement of Collaboration Network	0.06	0.05	0.05	0.06	0.05	0.05	0.08	0.07	0.07	0.07	0.07	0.06	0.08	0.08	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.07	0.07	0.06	0.03	0.03	0.04
Presence of change management	0.01	0.02	0.02	0.01	0.02	0.02	0.10	0.09	0.07	0.06	0.06	0.06	0.08	0.08	0.07	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.08	0.07	0.06	0.06	0.06	0.06

The Table 3.11 represents the normalized matrix based on the decision maker's responses and calculation done with the Fuzzy CoPrAs calculation. Once the decision matrix is formulated by taking average of 5 decision makers against parameters identified by the decision makers, normalized matrix is tabulated by calculation of normalizing with the weights assigned by the decision makers.

Determining of Weighted Normalized Decision-Making Matrix

$$N_{ij} = W_j \times n_{ij} \quad \ldots\ldots(4)$$

Table 3.12 Weighted Normalized Matrix for Fuzzy CoPrAs

Readiness Factors	Capability			Stability			Networking			Information Technology advantage			Extent of auto correct			Ease of collaboration with new devices			Decision making			Extent of Data Exchange			Extent of forecasting			Extend of up gradation			Cost involved			Time for implementation		
Requirement of Industrial Internet of Things (IIoT)	0.02	0.04	0.05	0.03	0.04	0.05	0.03	0.05	0.06	0.02	0.04	0.05	0.00	0.00	0.01	0.02	0.03	0.04	0.00	0.00	0.01	0.04	0.05	0.05	0.00	0.00	0.01	0.02	0.03	0.04	0.02	0.03	0.04	0.00	0.00	0.01
Level of digitization	0.00	0.01	0.02	0.00	0.01	0.02	0.03	0.05	0.06	0.03	0.04	0.06	0.00	0.01	0.02	0.02	0.03	0.04	0.00	0.01	0.03	0.04	0.05	0.05	0.00	0.00	0.02	0.02	0.03	0.04	0.04	0.06	0.06	0.03	0.04	0.05
Digital Capabilities	0.02	0.04	0.05	0.03	0.05	0.05	0.03	0.05	0.06	0.02	0.04	0.05	0.01	0.02	0.03	0.02	0.03	0.04	0.00	0.01	0.03	0.04	0.05	0.05	0.00	0.01	0.02	0.02	0.03	0.04	0.04	0.05	0.06	0.03	0.04	0.05
Capacity of Data Storage	0.03	0.04	0.05	0.03	0.05	0.05	0.01	0.01	0.02	0.01	0.03	0.04	0.00	0.01	0.02	0.02	0.03	0.04	0.00	0.01	0.02	0.04	0.05	0.05	0.00	0.00	0.00	0.02	0.03	0.04	0.04	0.05	0.06	0.00	0.00	0.01
Machine communication- Hardware component	0.03	0.04	0.05	0.03	0.05	0.05	0.04	0.06	0.06	0.02	0.04	0.05	0.00	0.01	0.02	0.01	0.02	0.04	0.00	0.00	0.01	0.04	0.05	0.05	0.00	0.00	0.00	0.02	0.03	0.04	0.03	0.05	0.06	0.00	0.00	0.01
Requirement of Data Driven services	0.02	0.04	0.05	0.03	0.05	0.05	0.03	0.05	0.06	0.03	0.04	0.06	0.01	0.02	0.04	0.02	0.03	0.04	0.00	0.01	0.03	0.04	0.05	0.05	0.00	0.01	0.02	0.02	0.03	0.04	0.04	0.05	0.06	0.03	0.04	0.05
Requirement of IOT platforms	0.03	0.04	0.05	0.04	0.05	0.05	0.04	0.05	0.06	0.02	0.03	0.05	0.00	0.00	0.01	0.01	0.03	0.04	0.00	0.01	0.03	0.02	0.03	0.04	0.00	0.00	0.01	0.02	0.03	0.04	0.04	0.06	0.06	0.03	0.04	0.05
Availability of Internet and Communicati	0.02	0.03	0.05	0.03	0.04	0.05	0.03	0.05	0.06	0.03	0.04	0.06	0.01	0.02	0.04	0.02	0.03	0.04	0.00	0.01	0.03	0.04	0.05	0.05	0.00	0.01	0.02	0.02	0.03	0.04	0.04	0.06	0.06	0.03	0.04	0.05

on Technology																																				
Availability of IT Integration software	0.02	0.04	0.05	0.03	0.05	0.05	0.03	0.05	0.06	0.03	0.04	0.06	0.01	0.02	0.04	0.02	0.03	0.04	0.00	0.01	0.03	0.04	0.05	0.05	0.00	0.01	0.02	0.02	0.03	0.04	0.04	0.06	0.06	0.01	0.02	0.03
Requirement of Knowledge about technology	0.01	0.02	0.03	0.02	0.03	0.04	0.00	0.01	0.02	0.02	0.03	0.05	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.03	0.04	0.05	0.05	0.00	0.01	0.02	0.02	0.03	0.04	0.00	0.00	0.01	0.03	0.04	0.05
Requirement of Calculating the Cost of technology	0.03	0.04	0.05	0.04	0.05	0.05	0.00	0.00	0.02	0.00	0.01	0.02	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.02	0.00	0.01	0.02	0.02	0.03	0.04	0.02	0.03	0.04	0.03	0.04	0.05
Requirement of calculating the Implementation cost	0.03	0.04	0.05	0.03	0.05	0.05	0.00	0.01	0.02	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.01	0.02	0.02	0.03	0.04	0.02	0.03	0.04	0.03	0.04	0.05
Requirement of Financial aid	0.02	0.04	0.05	0.03	0.04	0.05	0.00	0.01	0.02	0.00	0.01	0.02	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.02	0.00	0.01	0.02	0.02	0.03	0.04	0.02	0.03	0.04	0.03	0.04	0.05
Requirement of technology Proficiency	0.01	0.02	0.03	0.02	0.03	0.04	0.00	0.01	0.02	0.02	0.04	0.05	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.03	0.04	0.05	0.05	0.00	0.01	0.02	0.01	0.03	0.04	0.00	0.00	0.01	0.03	0.04	0.05
Availability of Leadership	0.02	0.04	0.05	0.03	0.04	0.05	0.00	0.00	0.02	0.00	0.01	0.02	0.01	0.02	0.04	0.02	0.03	0.04	0.00	0.01	0.03	0.02	0.04	0.04	0.00	0.01	0.02	0.02	0.03	0.04	0.02	0.03	0.04	0.03	0.04	0.05
Presence of long-term strategy	0.02	0.03	0.04	0.03	0.04	0.05	0.00	0.01	0.02	0.00	0.01	0.02	0.01	0.02	0.04	0.01	0.03	0.04	0.00	0.01	0.03	0.02	0.03	0.04	0.00	0.01	0.02	0.02	0.03	0.04	0.02	0.03	0.04	0.03	0.04	0.05

Requirement of Road map Strategy	0.03	0.04	0.05	0.04	0.05	0.05	0.00	0.01	0.02	0.00	0.01	0.02	0.01	0.02	0.04	0.01	0.03	0.04	0.00	0.01	0.03	0.01	0.02	0.03	0.00	0.01	0.02	0.02	0.03	0.04	0.02	0.03	0.04	0.03	0.04	0.05
Evaluation of digitization of supply chain	0.02	0.03	0.04	0.03	0.04	0.05	0.04	0.05	0.06	0.03	0.05	0.06	0.01	0.02	0.03	0.02	0.03	0.04	0.00	0.01	0.03	0.04	0.05	0.05	0.00	0.01	0.02	0.02	0.03	0.04	0.00	0.00	0.01	0.03	0.04	0.05
Requirement of Top management involvement and commitment	0.02	0.03	0.04	0.03	0.04	0.05	0.01	0.02	0.03	0.01	0.01	0.02	0.01	0.02	0.03	0.02	0.03	0.04	0.00	0.01	0.03	0.01	0.02	0.03	0.00	0.01	0.02	0.02	0.03	0.04	0.02	0.03	0.04	0.03	0.04	0.05
Requirement of Collaboration Network	0.02	0.04	0.05	0.03	0.05	0.05	0.03	0.05	0.06	0.02	0.04	0.05	0.01	0.02	0.03	0.01	0.03	0.04	0.00	0.01	0.03	0.03	0.05	0.05	0.00	0.01	0.02	0.02	0.03	0.04	0.04	0.05	0.06	0.01	0.02	0.04
Presence of change management	0.00	0.01	0.02	0.01	0.02	0.02	0.04	0.06	0.06	0.02	0.04	0.05	0.01	0.02	0.04	0.01	0.03	0.04	0.00	0.01	0.03	0.04	0.05	0.05	0.00	0.01	0.02	0.02	0.03	0.04	0.04	0.06	0.06	0.03	0.04	0.05

The Table 3.12 represents the weighted normalized matrix based on the decision maker's responses and calculated weights finalized by the decision makers. The weighted normalized matrix is the combination of weights formulated by giving the prioritizing the parameters to which these readiness factors will give the ranking among themselves. The weighted normalized matrix is then averaged and then sent for final ranking calculation.

Calculate the sum B_i of the Benefit Criteria values,

$$B_i = \sum_{j=1}^{k} N_{ij} \qquad \text{..........(5)}$$

Calculate the sum C_i of the Benefit Criteria values,

$$C_i = \sum_{j=k+1}^{k} N_{ij} \qquad \text{..........(6)}$$

Calculating the relative significance Q_i of each alternative

$$Q_i = B_i + \frac{\min(Ci).\sum_{i=1}^{n} Ci}{Ci.\sum_{i=1}^{n}(\frac{\min(Ci)}{Ci})} \qquad \text{.........(7)}$$

Determine the utility degree for each alternative as

$$UD_i = \frac{Qi}{\max(Qi)} \times 100\% \qquad \text{.........(8)}$$

Table 3.13 Final Ranking for Fuzzy CoPrAs

Readiness Factors	**FUZZY B_i BENEFIT VALUES**	**FUZZY C_i NON BENEFIT VALUES**		**FUZZY Min $(C_i)/C_i$**		**Q_i**		**UD_i**		**RANK**
Requirement of Industrial Internet of Things (IIoT) in Industry for implementation of INDUSTRY 4.0 in PPC	0.830	0.108		1.00		1.22		98%		2
Level of digitization of the organization for implementation of INDUSTRY 4.0 in PPC	0.752	0.278		0.39		0.90		72%		14
Digital Capabilities of the industry for implementation of INDUSTRY 4.0 in PPC	0.935	0.273		0.39		1.09		87%		7

Capacity of Data Storage of the industry for implementation of INDUSTRY 4.0 in PPC	0.737	0.164		0.66		1.0 0		79%		9
Machine communication-Hardware component for implementation of INDUSTRY 4.0 in PPC	0.866	0.153		0.71		1.1 4		91%		3
Requirement of Data Driven services in industry for implementation of INDUSTRY 4.0 in PPC	0.940	0.282		0.38		1.0 9		87%		6
Requirement of IOT platforms for implementation of INDUSTRY 4.0 in PPC	0.829	0.283		0.38		0.9 8		78%		10
Availability of Internet and Communication Technology in industry for implementation of INDUSTRY 4.0 in PPC	0.930	0.283		0.38		1.0 8		86%		8
Availability of IT Integration software for implementation of INDUSTRY 4.0 in PPC	0.940	0.224		0.48		1.1 3		90%		4
Requirement of Knowledge about technology in industry for implementation of INDUSTRY 4.0 in PPC	0.606	0.141		0.77		0.9 1		72%		12
Requirement of Calculating the Cost of technology for implementation of Industry 4.0 in PPC	0.480	0.213		0.51		0.6 8		54%		19

Requirement of calculating the Implementation cost for implementation of Industry 4.0 in PPC	0.431	0.219		0.49		0.62		50%		21
Requirement of Financial aid given for implementation of Industry 4.0 in PPC	0.455	0.211		0.51		0.66		52%		20
Requirement of technology Proficiency in industry for implementation of Industry 4.0 in PPC	0.595	0.137		0.79		0.90		72%		13
Availability of Leadership in industry for implementation of Industry 4.0 in PPC	0.681	0.228		0.47		0.87		69%		16
Presence of long term strategy in industry for implementation of Industry 4.0 in PPC	0.647	0.219		0.49		0.84		67%		18
Requirement of Road map Strategy in industry for implementation of Industry 4.0 in PPC	0.685	0.219		0.49		0.88		70%		15
Evaluation of digitization of supply chain in industry for implementation of Industry 4.0 in PPC	0.940	0.135		0.80		1.25		100%		1
Requirement of Top management involvement and commitment in industry for implementation of Industry 4.0 in PPC	0.658	0.220		0.49		0.85		68%		17

Requirement of Collaboration Network in industry for implementation of Industry 4.0 in PPC	0.919	0.224		0.48		1.11		88%		5
Presence of change management in industry for implementation of Industry 4.0 in PPC	0.796	0.286		0.38		0.94		75%		11

The Table 12 represents the final ranking calculation based on the decision maker's responses and Fuzzy CoPrAs calculation where benefit values and non-benefit values are calculated and then with the statistical calculation we get the most desirable ranks for the 21 readiness factors

A Mixed method approach is chosen to complete the objectives derived for the research.

3.8 Sample Design for Objective 2 & 3

The universe for this study includes all manufacturing industries with Tier 1 or Tier 2 vendors. The target population consists of top executives in Production Planning and Control from these manufacturing industries. The sampling unit is identified as the top assembly manufacturing industries located in the Pune region, while the sampling frame consists of the Production Planning and Control departments within these industries. The sample size is approximately one expert from the Production Planning and Control department of each of 10-15 industries.

This research employs probability sampling, specifically the cluster sampling method, due to the large size of the universe, which spans globally. Manufacturing industries with Tier 1 or Tier 2 vendors are treated as a homogeneous population, while automobile assembly units and related industries in Pune are classified as a heterogeneous population.

3.9 Research Tools

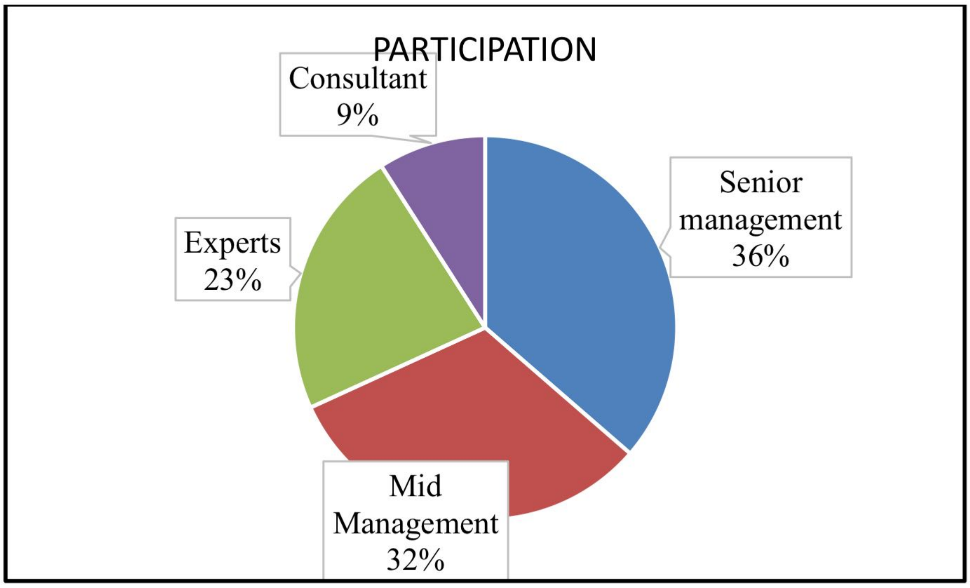
Fuzzy Delphi Method

The Fuzzy Delphi Method (FDM) combines fuzzy set theory with the traditional Delphi technique, initially introduced by Ishikawa (1993). According to Noorderhaven (1995), applying FDM in group decision-making helps address the uncertainties in shared understanding by incorporating expert opinions. FDM generates distinct sets of weights for various criteria based on these inputs.

The Delphi method itself is a structured process for gathering expert opinions, characterized by three key features: anonymous responses, controlled feedback, and iteration, leading to a statistical group response. Typically, Delphi allows experts to refine their answers after each round of questionnaires.

When combined with fuzzy theory, FDM offers additional benefits over the traditional Delphi method, such as reducing the time and cost associated with administering multiple questionnaires (Hsu, 2010; Yu-Feng, 2008). The Delphi process is a multi-round survey that helps achieve group consensus by allowing experts to adjust their responses based on feedback from previous rounds. In FDM, triangular fuzzy sets are employed along with fuzzy statistics and conjugate gradient search techniques to define the membership functions more precisely.

Figure 3.6 Levels of management involved



Source: author's own work

The questionnaire was such designed to take inputs from different management levels as mentioned in the Figure 02. The round one of this study constituted 40% of the total experts from mid management level, 25% from senior management level, 20% from Industry experts and 15% from consultants

Fuzzy Delphi Calculation

Table 3.14 Fuzzy Set for Delphi Study

Variable	Rating scale	Fuzzy Scale
Strongly disagree	1	(0.0, 0.1, 0.2)
Disagree	2	(0.1, 0.2, 0.4)
Not Sure	3	(0.2, 0.4, 0.6)
Agree	4	(0.4, 0.6, 0.8)
Strongly Agree	5	(0.6, 0.8, 1.0)

The above Fuzzy set in Table 3.14 is derived from the Fuzzy Triangular Number Matrix in which rating scale from 1 to 5 describes from Strongly disagree to Strongly Agree with three vertices as Strongly disagree with 0.0, 0.1 & 0.2 Disagree with 0.1, 0.2 & 0.4 people with neutral reaction or not sure about the decision will have 0.2, 0.4 & 0.6, Agree stands for 0.4, 0.6 & 0.8 and Strongly Agree means 0.6, 0.8 & 1.0. These Fuzzy sets will replace the rating scale for further Fuzzy calculation.

Data analysis is done with the help of Fuzzy Delphi and Fuzzy triangular Matrix. To view the degree of agreement among experts, a threshold value (d) for two fuzzy numbers m = (m1, m2, m3) and n = (m1, m2, m3) are calculated using the formula:

$$d= \tilde{m},\tilde{n} \sqrt{\frac{1}{3}[(m1-n1)^2+(m2-n2)^2+(m3-n3)^2} \qquad (1)$$

Step 1- Building of Likert scale table with the responses collected by 12 different Experts in 1-5 scale for individual 22 catalysts found by in depth literature review

Table 3.15 Likert scale for Catalysts

EXPERT	LIKERT SCALE																
	1	2	3	4	5	6	7	8	9	…	….	17	18	19	20	21	22
1	5	2	5	3	1	4	3	3	4	--	--	2	2	2	4	5	4
2	2	5	2	5	5	5	5	5	5	--	--	5	3	4	5	4	4
3	3	1	1	1	2	2	2	3	3	--	--	2	3	3	3	3	2
4	1	2	1	1	2	3	2	3	2	--	--	5	3	2	3	2	2
5	5	3	2	3	5	2	4	3	2	--	--	5	2	2	2	2	3
6	4	1	5	2	5	5	1	3	5	--	--	5	2	5	2	1	2
7	2	2	3	1	5	2	2	3	4	--	--	2	2	2	4	1	3
8	3	2	1	2	5	3	5	5	5	--	--	3	5	5	2	2	2
9	5	4	2	1	5	2	4	4	5	--	--	3	3	3	4	2	4
10	4	3	3	2	5	5	1	1	5	--	--	2	5	2	2	3	2
11	1	2	2	2	1	2	2	2	5	--	--	4	2	2	4	5	4
12	3	1	4	2	5	3	5	3	5	--	--	2	5	2	2	2	2

Table 3.16 Likert scale for impediments

	LIKERT SCALE															
EXPERT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	2	3	5	1	4	4	5	5	5	2	2	4	4	2	4	2
2	2	3	4	2	3	4	4	5	2	3	1	4	2	2	5	2
3	4	4	4	1	5	4	3	3	2	2	2	4	2	2	4	2

4	3	2	4	3	3	3	4	5	4	3	2	4	1	2	5	3
5	1	1	5	1	5	3	3	5	2	1	2	2	1	2	4	3
6	4	1	5	2	4	4	4	5	3	1	2	4	1	2	5	3
7	2	2	4	1	4	2	5	5	4	1	2	4	1	1	4	2
8	3	4	5	2	5	2	4	4	2	1	1	4	1	1	5	3
9	4	4	4	1	4	3	3	4	3	2	1	3	1	1	4	3
10	3	3	4	2	5	2	4	3	4	1	2	5	3	2	5	2
11	1	5	4	2	4	5	5	3	5	3	3	2	2	4	4	3
12	5	5	4	2	5	3	5	4	5	2	2	5	2	2	4	2

The above Table 3.15 & 3.16 represents the Likert scale in which 12 Decision makers Industries re considered for fuzzy Delphi and their input against each catalysts and impediments Industries re noted down in a tabulated column and given their rating scale as stated in Table-3.16 rating scale, where Strongly disagree stands as 1, Disagree stands as 2, Not sure stands as 3, Agree stands as 4 and Strongly agree stands as 5

Step 2- Building of Triangular Fuzzy scale matrix based on expert input

Table 3.17 Triangular Fuzzy scale matrix for Catalyst

EXPERT	FUZZY SCALE														
	1			2			----			21			22		
1	0.6	0.8	1	0	0.8	0.4	--	--	--	0.2	0.4	0.6	0	0	0.2
2	0	0.2	0.4	0.6	0.8	1	--	--	--	0.6	0.8	1	0.6	0.8	1
3	0.2	0.4	0.6	0	0	0.2	--	--	--	0	0	0.2	0	0.2	0.4
4	0	0	0.2	0	0.2	0.4	--	--	--	0	0	0.2	0	0.2	0.4

5	0.6	0.8	1	0.2	0.4	0.6	- -	- -	- -	0.2	0.4	0.6	0.6	0.8	1
6	0.4	0.6	0.8	0	0	0.2	- -	- -	- -	0	0.2	0.4	0.6	0.8	1
7	0	0.2	0.4	0	0.2	0.4	- -	- -	- -	0	0	0.2	0.6	0.8	1
8	0.2	0.4	0.6	0	0.2	0.4	- -	- -	- -	0	0.2	0.4	0.6	0.8	1
9	0.6	0.8	1	0.4	0.6	0.8	- -	- -	- -	0	0	0.2	0.6	0.8	1
10	0.4	0.6	0.8	0.2	0.4	0.6	- -	- -	- -	0	0.2	0.4	0.6	0.8	1
11	0	0	0.2	0	0.2	0.4	- -	- -	- -	0	0.2	0.4	0	0	0.2
12	0.2	0.4	0.6	0	0	0.2	- -	- -	- -	0	0.2	0.4	0.6	0.8	1
AVERAGE	0.300	0.478	0.678	0.144	0.344	0.511	- -	- -	- -	0.122	0.278	0.478	0.378	0.544	0.744
	m1	m2	m3	m1	m2	m3	- -	- -	- -	m1	m2	m3	m1	m2	m3

Table 3.18 Triangular Fuzzy scale matrix for Impediments

EXPERT	LIKERT SCALE													
	1			2					15			16		
1	0	0.2	0.8	0.2	0.4	0.6	- -	- -	0.4	0.6	0.8	0	0.2	0.8
2	0	0.2	0.8	0.2	0.4	0.6	- -	- -	0.6	0.8	1	0	0.2	0.8
3	0.4	0.6	0.8	0.4	0.6	0.8	- -	- -	0.4	0.6	0.8	0	0.2	0.8

4	0.2	0.4	0.6	0	0.2	0.8	- -	- -	0.6	0.8	1	0.2	0.4	0.6
5	0	0.1	0.0.8	0	0.1	0.0.8	- -	- -	0.4	0.6	0.8	0.2	0.4	0.6
6	0.4	0.6	0.8	0	0.1	0.0.8	- -	- -	0.6	0.8	1	0.2	0.4	0.6
7	0	0.2	0.8	0	0.2	0.8	- -	- -	0.4	0.6	0.8	0	0.2	0.8
8	0.2	0.4	0.6	0.4	0.6	0.8	- -	- -	0.6	0.8	1	0.2	0.4	0.6
9	0.4	0.6	0.8	0.4	0.6	0.8	- -	- -	0.4	0.6	0.8	0.2	0.4	0.6
10	0.2	0.4	0.6	0.2	0.4	0.6	- -	- -	0.6	0.8	1	0	0.2	0.8
11	0	0.1	0.0.8	0.6	0.8	1	- -	- -	0.4	0.6	0.8	0.2	0.4	0.6
12	0.6	0.8	1	0.6	0.8	1	- -	- -	0.4	0.6	0.8	0	0.2	0.8
Avg	0.2	0.38	0.76	0.25	0.43	0.78	- -	- -	0.48	0.68	0.88	0.1	0.3	0.7
	m1	m2	m3	m1	m2	m3			m1	m2	m3	m1	m2	m3

The above Table 3.17 & 3.18 is the driven out Triangular Fuzzy scale in which the outputs received by the various decision makers against each 22 catalysts and 16 impediments are formulated based on the Fuzzy sets tabulated in the Table 3.14. The table stands as Strongly disagree with 0.0, 0.1 & 0.2 Disagree with 0.1, 0.2 & 0.4 people with neutral reaction or not sure about the decision will have 0.2, 0.4 & 0.6, Agree stands for 0.4, 0.6 & 0.8 and Strongly Agree means 0.6, 0.8 & 1.0. These Fuzzy sets will replace the rating scale for further Fuzzy calculation. In this average of each column is calculated and denoted as m1, m2, m3 respectively for each Readiness factor decisions given by 12 decision makers.

Step 3- Finding out the threshold "d" value

Table 3.19 Threshold matrix

EXPERT	ITEM								
	1	2	3	-----	-----	19	20	21	22
1	0.5	0.5	0.4	---	---	0.3	0.0	0.1	0.0
2	0.4	0.3	0.5	---	---	0.6	0.6	0.5	0.3
3	0.6	0.5	0.4	---	---	0.3	0.3	0.1	0.3
4	0.7	0.2	0.5	---	---	0.0	0.3	0.1	0.6
5	0.5	0.1	0.5	---	---	0.3	0.3	0.1	0.6
6	0.2	0.5	0.5	---	---	0.6	0.6	0.1	0.3
7	0.4	0.2	0.4	---	---	0.3	0.3	0.1	0.0
8	0.3	0.2	0.1	---	---	0.0	0.6	0.5	0.3
9	0.5	0.4	0.1	---	---	0.3	0.3	0.2	0.3
10	0.2	0.1	0.4	---	---	0.6	0.6	0.7	0.3
11	0.7	0.2	0.2	---	---	0.3	0.3	0.4	0.3
12	0.7	0.5	0.4	---	---	0.0	0.6	0.1	0.3
Value of d each item	0.475	0.308	0.367			0.300	0.400	0.250	0.475
Value of d construct	0.350								

The calculations in Table 3.19 determined the individual threshold value (d) for all 22 catalysts and 16 impediments as 0.350, based on an extensive literature review. Using the criteria of d≤0.2d \leq 0.2d≤0.2 and achieving an expert group consensus of over 75%, the analysis identified 9 catalysts and 9 impediments as the most impactful catalysts and the most critical impediments to avoid for successfully implementing Industry 4.0 in Production Planning and Control. The constructive values were determined by defuzzifying the fuzzy matrix using the threshold value formula. The average of each column was then calculated to establish the threshold for each readiness factor and to evaluate them based on group consensus. This approach aligns with the findings of Singh, Nasir, and Khan (2020), who highlighted the importance of overcoming hurdles and leveraging catalysts in the adoption and implementation of Industry 4.0 technologies in Indian automotive industries.

Fuzzy Delphi result

For Catalyst

Technology upgradation

- Digitization
- Connectivity
- Competitive edge
- Business KPI
- Leadership
- Application
- ROBOTS
- IOT based system

For Impediments

- Low level leadership
- Central Data ownership
- Inhouse talent
- Integration with existing networking
- High-fi level knowledge building
- IT prerequisite
- Budget allocation
- Forecasting immediate return

- High labour volume

After calculating with Fuzzy Delphi study Industries got to know that 12 different experts have suggested that 9 different catalysts and 9 different impediments are to be considered for implementation of Industry 4.0 in Production planning and control. With the completion of Fuzzy Delphi Study, 22 catalysts and 16 impediments got reduced to 9 effective catalysts and 9 impediments.

3.10 BWM Method

Rezaei (2015) introduced BWM (Best Worst Method), and Guo and Zhao (2017) developed BWM. Initially, determine the decision goal and identify the various criteria to evaluate any decision-making problem. BWM is not a matrix based MCDM method, but it is a vector based method with Industries comparisons.

The BWM is a method that has been derived and developed to solve MCDM problems (Rezaei, 2015, 2016) and that is based on pairwise comparison based on vector calculation. BWM has two key advantages over other MCDM approaches of decision making -:

i) Comparison data needed is less compared to full pairwise matrix.

ii) The results of BWM are more consistent than other MCDM methods.

This method is getting utilized in several real-world issues. For example, Rezaei et al. (2016a) used BWM for determining best freight bundling configuration from outstations to airports. In another study by Rezaei et al. (2016b), best suppliers were selected considering environmental and economic criteria.

Determination of decision criteria

In the initial stage, decision-makers identified a set of criteria relevant to the subject matter. This section outlines the development and refinement processes of the study. The criteria for catalysts and impediments were determined through an extensive literature review, supplemented by input from 12 senior decision-makers from leading automotive industries. These individuals hold top-level positions within their respective organizations. Based on the literature review, four criteria each for catalysts and impediments were initially selected by the decision-makers. The experts were provided with a questionnaire containing these criteria and asked to rate them on a scale of 1 to 5, where 1 indicated low relevance and 5 indicated high relevance. Following this process, eight criteria—four for catalysts and four for impediments—were finalized as the most relevant, based on the ratings and expert consensus.

Table 3.20 Criteria selected for the assessment of Catalyst

Criteria	Criteria ABB	Short description
Technological Readiness	C1	Technology needs to be analysed for its readiness for implementing Industry 4.0 in any Industry
Technology security	C2	Online platforms where data needs to be secured for any business-related data transfer
Organizational readiness	C3	Organization updates for incorporating new technology and internet based readiness for any industry
Financial commitment	C4	Having required budget and commitment from senior management for implementation of Industry 4.0 projects

Table 3.21 Criteria selected for the assessment of Impediments

Criteria	Criteria ABB	Short description
Budgetary approval process	I1	Budget approval process should not be lengthy and time taking
Implementation timeline	I2	Implementation timeline should be mapped and forecasted before project initiation
Leadership	I3	Involvement of senior leadership is required
Organizational readiness	I4	Organization updates for incorporating new technology and internet based readiness for any industry

Identifying the best and the worst catalyst and impediments

In the second phase, the nine criteria for assessing catalysts and impediments were shared, along with the list of catalysts and impediments identified through the Fuzzy Delphi study, with 178 respondents from leading automotive manufacturers nationwide. The ratings for each catalyst and impediment were provided based on the criteria established by the 12 senior decision-makers, which highlighted the most and least significant catalysts and impediments.

From the analysis, the top-rated catalyst was identified as "Connectivity," while the least significant catalyst was "Technology Upgradation." Similarly, the most critical impediment was determined to be "Low-Level Leadership," whereas "Budget" was rated as the least critical impediment. The outcomes, including the top and bottom ratings, are summarized in Table 3.21

BWM calculation for Catalysts

Table 3.22 BWM sheet for catalysts

Names of Criteria	Technology upgradation	Digitization	Connectivity	Competitive edge	Business KPI	Leadership	Application	ROBOTS	IOT based system

Select the Best	Connectivity
Select the Worst	Technology

Best to Others	Technology upgradation	Digitization	Connectivity	Competitive edge	Business KPI	Leadership	Application	ROBOTS	IOT based system
Connectivity	4	2	1	6	3	1	5	5	2

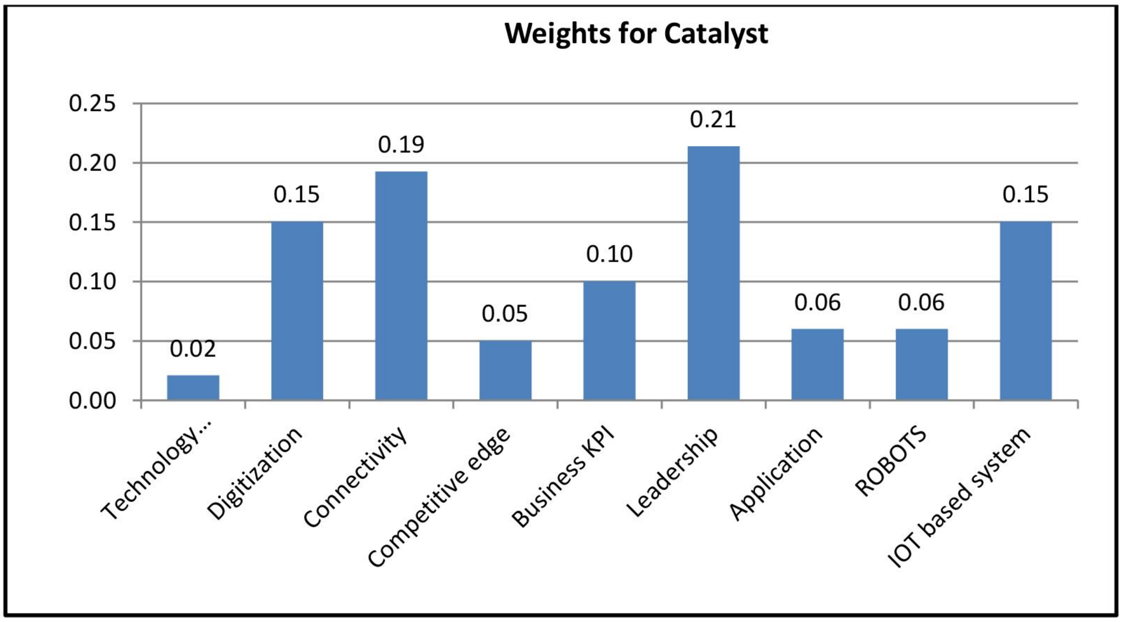
Others to the Worst	Technology
Technology	1
Digitization	4
Connectivity	7
Competitive edge	3
Business KPI	7
Leadership	5
Application	8
ROBOTS	3
IOT based system	2

Weights	Technology upgradation	Digitization	Connectivity	Competitive edge	Business KPI	Leadership	Application	ROBOTS	IOT based system
	0.02	0.15	0.19	0.05	0.10	0.21	0.06	0.06	0.15

Ksi*	0.10843373

Source: author’s own work

Figure 3.7 – Weights for the catalyst



Source: Singh et al. (2024)

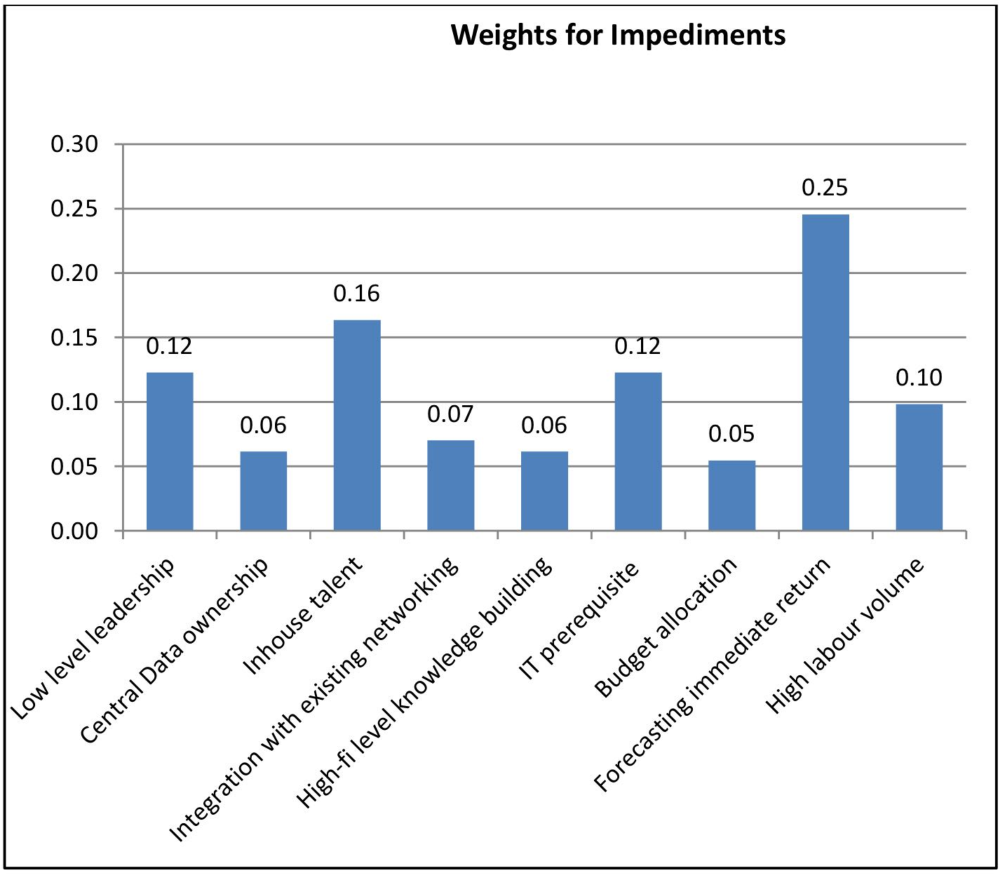
BWM calculation for Impediments

Table 3.23 BWM sheet for Impediments

Names of Criteria	Low level leadership	Central Data ownership	Inhouse talent	Integration with existing networking	High-fi level knowledge building	IT prerequisite	Budget allocation	Forecasting immediate return	High labour volume
Select the Best	Low level								
Select the Worst	Budget								
Best to Others	Low level leadership	Central Data ownership	Inhouse talent	Integration with existing networking	High-fi level knowledge building	IT prerequisite	Budget allocation	Forecasting immediate return	High labour volume
Low level leadership	4	8	3	7	8	4	9	2	5
Others to the Worst	Budget								
Low level leadership	9								
Central Data	5								
Inhouse talent	6								
Integration with	6								
High-fi level	8								
IT prerequisite	4								
Budget allocation	8								
Forecasting immediate	3								
High labour volume	5								
Weights	Low level leadership	Central Data ownership	Inhouse talent	Integration with existing networking	High-fi level knowledge building	IT prerequisite	Budget allocation	Forecasting immediate return	High labour volume
	0.12	0.06	0.16	0.07	0.06	0.12	0.05	0.25	0.10
Ksi*	0.4908453								

After performing various statistical calculation among respondents for the preference of the decision-maker on "the Best criterion over all the other criteria", and the preference of "all the other criteria over the Worst" by selecting a number 1 and 9 from the drop-box, the above bar graph represents the industries weights of catalyst.

Figure 3.8 Weights for the Impediments



Source: Singh et al. (2024)

After performing various statistical calculation among respondents for the preference of the decision-maker on "the Best criterion over all the other criteria", and the preference of "all the other criteria over the Worst" by picking up a number 1 and 9 from the drop-box, the above bar graph represents the industries weights of impediments

3.11 Fuzzy ISM

Fuzzy ISM helps in getting the pictorial representation of interrelation between the elements mapped. Here in this article Fuzzy ISM is conducted for most important Catalysts and biggest hurdles separately.

For fuzzy set, Triangular Fuzzy matrix has been considered for evaluation

Table 3.24 Triangular Fuzzy matrix for Fuzzy ISM

TRIANGULAR NUMBER	VARIABLE	SYMBOL
0.75,1,1	VERY STRONG	AR.
0.5,0.75,1	STRONG	SR
0.25,0.5,0.75	RELATIVELY	FR
0.0,0.25,0.5	WEAK	LR
0,0,0.25	VERY WEAK	UN

For catalysts, below the Structural Self Interaction Matrix is considered for observation collection

Table 3.25 Structural Self Interaction Matrix for Catalyst

		Competitive edge	ROBOTS	Application	Business KPI	IOT based system	Digitization	Connectivity	Leadership
	FACTORS	8	7	6	5	4	3	2	1
Leadership	1	0.89	0.63	0.22	0.97	0.8	0.94	0.14	0.92
Connectivity	2	0.25	0.87	0.87	0.16	0.8	0.86	0.86	0.19
Digitization	3	0.74	0.89	0.53	0.48	0.8	0.86	0.87	0.12
IOT based system	4	0.49	0.78	0.23	0.12	0.8	0.90	0.87	0.24
Business KPI	5	0.86	0.28	0.24	0.85	0.1	0.76	0.26	0.87
Application	6	0.80	0.85	0.86	0.52	0.8	0.84	0.46	0.14
ROBOTS	7	0.78	0.91	0.91	0.16	0.8	0.89	0.88	0.23
Competitive edge	8	0.90	0.78	0.15	0.70	0.5	0.79	0.25	0.88

For Impediments, below Structural Self Interaction Matrix is considered for observation collection

Table 3.26 Structural Self Interaction Matrix for Impediments

		Budget allocation	High-fi level knowledge building	Central Data ownership	Integration with existing networking	High labour volume	IT prerequisite	Low level leadership	Inhouse talent	Forecasting immediate return
	FACTORS	9	8	7	6	5	4	3	2	1
Forecasting immediate return	1	0.87	0.14	0.13	0.25	0.50	0.88	0.75	0.75	0.88
Inhouse talent	2	0.50	0.16	0.75	0.85	0.85	0.14	0.86	0.88	0.75
Low level leadership	3	0.86	0.76	0.50	0.86	0.75	0.25	0.88	0.75	0.88
IT prerequisite	4	0.86	0.87	0.87	0.76	0.13	0.88	0.12	0.11	0.25
High labour volume	5	0.83	0.14	0.14	0.50	0.86	0.13	0.85	0.86	0.25

Integration with existing networking	6	0.75	0.86	0.85	0.84	0.75	0.75	0.75	0.87	0.13
Central Data ownership	7	0.83	0.75	0.83	0.83	0.16	0.84	0.50	0.50	0.16
High-fi level knowledge building	8	0.84	0.85	0.13	0.50	0.14	0.75	0.15	0.86	0.75
Budget allocation	9	0.87	0.87	0.86	0.86	0.87	0.85	0.86	0.75	0.14

The observations we collected in form of digital survey and converted to Fuzzy logic based on Fuzzy set for catalyst.

Table 3.27 Fuzzy Structural Self Interaction Matrix for Catalyst

		Competiti			ROBOTS			Applicati			Busines			IOTbase			Digitiza			Connecti			Leaders		

		veedge						on			sKPI			dsystem			tion			vity			hip		
	FACTORS	8			7			6			5			4			3			2			1		
Leadership	1	0.89	0.79	1.00	0.60	0.53	0.78	0.31	0.05	0.30	0.93	0.98	1.00	0.67	0.75	1.00	0.83	0.98	1.00	0.10	0.04	0.29	0.76	1.00	1.00
Connectivity	2	0.04	0.23	0.48	0.70	0.93	0.99	0.71	0.93	0.97	0.04	0.09	0.33	0.69	0.93	1.00	0.67	0.92	1.00	0.68	0.92	0.97	0.06	0.14	0.38
Digitization	3	0.50	0.75	0.98	0.72	0.96	0.99	0.28	0.53	0.77	0.24	0.48	0.73	0.69	0.94	1.00	0.66	0.91	1.00	0.69	0.94	1.00	0.00	0.05	0.30
IOT based system	4	0.25	0.49	0.73	0.55	0.80	1.00	0.01	0.22	0.47	0.01	0.05	0.30	0.71	0.96	1.00	0.72	0.97	1.00	0.69	0.94	1.00	0.00	0.23	0.48
Busines	5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	0.	0.	0.	0.	0.	0.

s KPI		68	93	99	03	28	52	00	24	49	68	92	97	03	08	32	52	77	00	03	25	49	69	94	98
Application	6	0.58	0.83	1.00	0.66	0.91	0.98	0.68	0.93	0.98	0.27	0.52	0.76	0.69	0.93	0.97	0.63	0.88	1.00	0.22	0.46	0.71	0.03	0.08	0.32
ROBOTS	7	0.55	0.80	1.00	0.73	0.98	1.00	0.73	0.98	1.00	0.04	0.10	0.35	0.68	0.93	1.00	0.71	0.96	1.00	0.70	0.95	0.99	0.00	0.22	0.47
Competitive edge	8	0.73	0.98	1.00	0.55	0.80	1.00	0.03	0.08	0.32	0.47	0.70	0.93	0.27	0.51	0.75	0.56	0.81	1.00	0.03	0.24	0.48	0.70	0.95	0.97

The observations we collected in the form of digital survey and converted to Fuzzy logic based on Fuzzy set for impediments.

Table 3.28 Fuzzy Structural Self Interaction Matrix for Impediments

		Budget alloca			High-fi level			Central Data o			Integration w			Highlabour v			IT prerequis			Low level lea			Inhouse tale			Forecasting i		

		tion			knowledgebuilding			wnership			ithexistingnetworking			olume			ite			dership			nt			mmediatereturn		
	FACTORS	9			8			7			6			5			4			3			2			1		
Forecastin	1	0.68	0.93	1.00	0.00	0.09	0.34	0.00	0.08	0.33	0.00	0.25	0.50	0.25	0.50	0.75	0.69	0.94	1.00	0.50	0.75	1.00	0.50	0.75	1.00	0.70	0.95	1.00

g immediate return																												
Inhouse talent	2	0.25	0.50	0.75	0.00	0.11	0.36	0.50	0.75	1.00	0.65	0.90	1.00	0.65	0.90	1.00	0.00	0.09	0.34	0.66	0.91	1.00	0.69	0.94	1.00	0.50	0.75	1.00
Lowle	3	0.66	0.91	1.00	0.51	0.76	1.00	0.25	0.50	0.75	0.66	0.91	1.00	0.50	0.75	1.00	0.00	0.25	0.50	0.69	0.94	1.00	0.50	0.75	1.00	0.70	0.95	1.00

velleadership																												
ITprerequisite	4	0.66	0.91	1.00	0.68	0.93	1.00	0.68	0.93	1.00	0.51	0.76	1.00	0.00	0.08	0.33	0.69	0.94	1.00	0.00	0.05	0.30	0.00	0.04	0.29	0.00	0.25	0.50
Highlabou	5	0.63	0.88	1.00	0.00	0.09	0.34	0.00	0.09	0.34	0.25	0.50	0.75	0.66	0.91	1.00	0.00	0.08	0.33	0.65	0.90	1.00	0.66	0.91	1.00	0.00	0.25	0.50

r volume																												
Integration with existing networki	6	0.50	0.75	1.00	0.66	0.91	1.00	0.65	0.90	1.00	0.64	0.89	1.00	0.50	0.75	1.00	0.50	0.75	1.00	0.50	0.75	1.00	0.68	0.93	1.00	0.00	0.08	0.33

ng																												
Central Data ownership	7	0.63	0.88	1.00	0.50	0.75	1.00	0.61	0.86	1.00	0.63	0.88	1.00	0.00	0.11	0.36	0.64	0.89	1.00	0.25	0.50	0.75	0.25	0.50	0.75	0.00	0.11	0.36
High-file level kn	8	0.64	0.89	1.00	0.65	0.90	1.00	0.00	0.08	0.33	0.25	0.50	0.75	0.00	0.09	0.34	0.50	0.75	1.00	0.00	0.10	0.35	0.66	0.91	1.00	0.50	0.75	1.00

owledge building																												
Budget allocation	9	0.68	0.93	1.00	0.68	0.93	1.00	0.66	0.91	1.00	0.66	0.91	1.00	0.68	0.93	1.00	0.65	0.90	1.00	0.66	0.91	1.00	0.50	0.75	1.00	0.00	0.09	0.34

Once the matrix is defuzzied, then the matrix is reconverted into Boolean logic where 0 and 1 are considered.

Table 3.29 Defuzzied Structural Self Interaction Matrix for Catalyst

CATALYSTS		Competitive edge	ROBOTS	Application	Business KPI	IOT based system	Digitization	Connectivity	Leadership	
	FACTORS	8	7	6	5	4	3	2	1	
Leadership	1	1	0	0	1	0	1	0	1	4
Connectivity	2	0	1	1	0	1	1	1	0	5
Digitization	3	0	1	0	0	0	0	0	0	1
IOT based system	4	0	0	0	0	1	1	0	0	2
Business KPI	5	1	0	0	1	0	0	0	0	2
Application	6	0	0	1	0	0	0	0	0	1
ROBOTS	7	0	1	1	0	0	1	0	0	3
Competitive edge	8	1	0	0	0	0	1	0	0	2
		3	3	3	2	2	5	1	1	

Table 3.30 Defuzzyfied Structural Self Interaction Matrix for Impediments

IMPEDIMENTS		Budget allocation	High-fi level knowledge building	Central Data ownership	Integration with existing networking	High labour volume	IT prerequisite	Low level leadership	Inhouse talent	Forecasting immediate return	
	FACTORS	9	8	7	6	5	4	3	2	1	
Forecasting immediate return	1	1	0	0	0	0	1	0	0	1	3
Inhouse talent	2	0	0	0	0	0	0	0	1	0	1
Low level leadership	3	0	0	0	0	0	0	1	0	1	2
IT prerequisite	4	0	1	1	0	0	1	0	0	0	3
High labour volume	5	0	0	0	0	1	0	0	1	0	2
Integration with existing	6	0	1	1	1	0	0	0	1	0	4

networking											
Central Data ownership	7	1	0	1	1	0	1	0	0	0	4
High-fi level knowledge building	8	1	1	0	0	0	0	0	1	0	3
Budget allocation	9	1	1	0	0	0	0	0	0	0	2
		4	4	3	2	1	3	1	4	2	

Next step is to check the transitivity of the matrix based on the factors identified for Catalyst and Impediments

Table 3.31 Transitivity Matrix for Catalyst

CATALYSTS	Competitive edge	ROBOTS	Application	Business KPI	IOT based system	Digitization	Connectivity	Leadership	**DRIVING POWER**
FACTORS	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	
1	1	1	0	1	0	1	0	1	**5**
2	0	1	1	0	1	1	1	0	**5**
3	0	1	1	0	0	1	0	0	**3**
4	0	1	0	0	1	1	0	0	**3**
5	1	0	0	1	0	1	0	0	**3**
6	0	0	1	0	0	1	0	0	**2**

7	0	1	1	0	0	1	0	0	**3**
8	1	0	0	0	0	1	0	0	**2**
DEPENDENCE	**3**	**5**	**4**	**2**	**2**	**8**	**1**	**1**	

Table 3.32 Transitivity Matrix for Impediments

IMPEDIMENTS	Budget allocation	High-fi level knowledge building	Central Data ownership	Integration with existing networking	High labour volume	IT prerequisite	Low level leadership	Inhouse talent	Forecasting immediate return	**DRIVING POWER**
FACTORS	9	8	7	6	5	4	3	2	1	
1	1	1	1	0	0	1	0	0	1	**5**
2	0	0	0	0	0	0	0	1	0	**1**
3	1	0	0	0	0	1	1	0	1	**4**
4	0	1	1	0	0	1	0	0	0	**3**
5	0	0	0	0	1	0	0	1	0	**2**
6	0	1	1	1	0	0	0	1	0	**4**
7	1	1	1	1	0	1	0	1	0	**6**
8	1	1	0	0	0	0	0	1	0	**3**
9	1	1	0	0	0	0	0	1	0	**3**
DEPENDENCE	**5**	**6**	**4**	**2**	**1**	**4**	**1**	**6**	**2**	

Once the transitivity matrix is prepared, Initial Reachability matrix is prepared before level partitioning

Table 3.33 Reachability Matrix for Catalysts

CATALYSTS	**FACTORS**	**Leadership**	**Connectivity**	**Digitization**	**IOT based system**	**Business KPI**	**Application**	**ROBOTS**	**Competitive edge**	**DRIVING POWER**
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
Leadership	**1**	1	0	1	0	1	0	1	1	**5**
Connectivity	**2**	0	1	1	1	0	1	1	0	**5**
Digitization	**3**	0	0	1	0	0	1	1	0	**3**
IOT based system	**4**	0	0	1	1	0	0	1	0	**3**
Business KPI	**5**	0	0	1	0	1	0	0	1	**3**
Application	**6**	0	0	1	0	0	1	0	0	**2**
ROBOTS	**7**	0	0	1	0	0	1	1	0	**3**
Competitive edge	**8**	0	0	1	0	0	0	0	1	**2**
DEPENDENCE		**1**	**1**	**8**	**2**	**2**	**4**	**5**	**3**	

Table 3.34 Reachability Matrix for Impediments

IMPEDIMENTS		**Forecasting immediate**	**In-house tal**	**Low level leadership**	**IT prerequisite**	**High labour vol**	**Integration with existing netw**	**Central Data ownership**	**High-fi level knowledge**	**Budget allocation**	**DRIVING POWER**

		retu rn	**en t**			**u me**	**orki ng**		**buil ding**		
	FAC TO RS	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Forecasting immediate return	**1**	1	1	1	0	0	1	1	0	1	**6**
Inhouse talent	**2**	0	1	0	0	1	0	0	0	0	**2**
Low level leadership	**3**	0	0	1	0	0	1	1	0	1	**4**
IT prerequisite	**4**	0	1	1	1	0	1	0	0	0	**4**
High labour volume	**5**	0	0	0	0	1	0	0	1	0	**2**
Integration with existing networking	**6**	0	1	1	0	0	1	0	1	0	**4**
Central Data ownership	**7**	1	1	0	1	0	1	1	1	0	**6**
High-fi level knowledge building	**8**	1	1	0	0	0	0	0	1	1	**4**
Budget allocation	**9**	1	1	0	0	0	0	0	1	1	**4**
DEPENDEN CE		**4**	**7**	**4**	**2**	**2**	**5**	**3**	**5**	**4**	

Table 3.35 Level-1 Partitioning of the catalysts

LEVEL 1 PARTITIONING	CATALYST				
	FACTORS	REACHABILITY SET	ANTECEDENT SET	INTERSECTION SET	LEVEL
	1	1,3,5,7,8	1,5		
	2	2,3,4,6,7	2	2	I
	3	3,6,7	1,2,3,4,5,6,7,8		
	4	2,3,4,7	2,4,6		
	5	1,3,5,8	1,5		
	6	3,4,6	2,3,6,7	3	I
	7	3,4,6,7	1,2,3,4,7		
	8	3,8	1,5,8	8	I

Table 3.36 Level-2 Partitioning of the catalysts

LEVEL 2 PARTITIONING	CATALYST				
	FACTORS	REACHABILITY SET	ANTECEDENT SET	INTERSECTION SET	LEVEL
	1	1,3,5,7	1	1	II
	2				
	3	3,7	1,3,4,5,7		
	4	3,4,7	4,6		
	5	1,3,5	1,5		
	6				
	7	3,4,7	1,3,4,7		
	8				

Table 3.37 Level-3 Partitioning of the catalysts

LEVEL 3 PARTITIONING	CATALYST				
	FACTORS	REACHABILITY SET	ANTECEDENT SET	INTERSECTION SET	LEVEL
	1				
	2				
	3	3,7	3,4,5,7		
	4	3,4,7	4	4	III
	5	3,5	5	5	III
	6				
	7	3,4,7	3,4,7		
	8				

Table 3.38 Level-4 Partitioning of the catalysts

LEVEL 4 PARTIONING	CATALYST				
	FACTORS	REACHABILITY SET	ANTECEDENT SET	INTERSECTION SET	LEVEL
	1				
	2				
	3	3,7	3,7	3	IV
	4				
	5	3,5	5		
	6				
	7	3,7	3,7	7	IV
	8				

Level partitioning of Impediments

Table 3.39 Level-1 Partitioning of the Impediments

	IMPEDIMENTS				
LEVEL 1 PARTITIONING	FACTORS	REACHABILITY SET	ANTECEDENT SET	INTERSECTION SET	LEVEL
	1	1,2,3,6,7,9	1,7,8,9		
	2	2,5	1,2,4,6,7,8,9		
	3	1,3,6,7,9	1,3,4,6,7		
	4	2,3,4,6	4,6,7		
	5	5,8	5	5	I
	6	2,3,6,8	1,3,4,6,7		
	7	1,2,4,6,7,8	3,7		
	8	1,2,8	2,5,6,7,8,9		
	9	1,2,8,9	1,3,8,9		

Table 3.40 Level-2 Partitioning of the Impediments

	IMPEDIMENTS				
LEVEL 2 PARTITIONING	FACTORS	REACHABILITY SET	ANTECEDENT SET	INTERSECTION SET	LEVEL
	1	1,2,3,6,7,9	1,7,8,9		
	2	2	1,2,4,6,7,8,9	2	II
	3	1,3,6,7,9	1,3,4,6,7		
	4	2,3,4,6	4,6,7		
	5	5,8	5		
	6	2,3,6,8	1,3,4,6,7		
	7	1,2,4,6,7,8	3,7		
	8	1,2,8	2,6,7,8,9		
	9	1,2,8,9	1,3,8,9		

Table 3.41 Level-3 Partitioning of the Impediments

	IMPEDIMENTS				
LEVEL 3 PARTITIONING	FACTORS	REACHABILITY SET	ANTECEDENT SET	INTERSECTION SET	LEVEL
	1	1,3,6,7,9	1,7,8,9		
	2	2	1,2,4,6,7,8,9		
	3	1,3,6,7,9	1,3,4,6,7		
	4	3,4,6	4,6,7		
	5	5,8	5		
	6	3,6,8	1,3,4,6,7		
	7	1,4,6,7,8	3,7		
	8	1,8	6,7,8,9	8	III
	9	8,9	1,3,8,9		

Table 3.42 Level-4 Partitioning of the Impediments

	IMPEDIMENTS				
LEVEL 4 PARTITIONING	FACTORS	REACHABILITY SET	ANTECEDENT SET	INTERSECTION SET	LEVEL
	1	1,3,6,7,9	1,7,9		
	2	2	1,2,4,6,7,8,9		
	3	1,3,6,7,9	1,3,4,6,7		
	4	3,4,6	4,6,7		
	5	5,8	5		
	6	3,6	1,3,4,6,7		
	7	1,4,6,7	3,7		
	8	1,8	6,7,8,9		
	9	9	1,3,9	9	IV

Table 3.43 Level-5 Partitioning of the Impediments

	IMPEDIMENTS				
LEVEL 5 PARTITIONING	FACTORS	REACHABILITY SET	ANTECEDENT SET	INTERSECTION SET	LEVEL
	1	1,3,6,7	1,7		
	2	2	1,2,4,6,7,8,9		
	3	1,3,6,7	1,3,4,6,7		
	4	3,4,6	4,6,7		
	5	5,8	5		
	6	3,6	1,3,4,6,7		
	7	1,4,6,7	3,7	7	V
	8				
	9				

Table 3.44 Level-6 Partitioning of the Impediments

	IMPEDIMENTS				
LEVEL 6 PARTITIONING	FACTORS	REACHABILITY SET	ANTECEDENT SET	INTERSECTION SET	LEVEL
	1	1,3,6	1	1	VI
	2	2	1,2,4,6,7,8,9		
	3	1,3,6	1,3,4,6		
	4	3,4,6	4,6		
	5	5,8	5		
	6	3,6	1,3,4,6		
	7				
	8				
	9				

Table 3.47 Level-7 Partitioning of the Impediments

	IMPEDIMENTS				
LEVEL 7 PARTITIONI NG	FACTOR S	REACHABILI TY SET	ANTECEDE NT SET	INTERSECTI ON SET	LEVE L
	1				
	2				
	3	3,6	3,4,6	3	VII
	4	3,4,6	4,6		
	5	5,8	5		
	6	3,6	3,4,6	6	VII
	7				
	8				
	9				

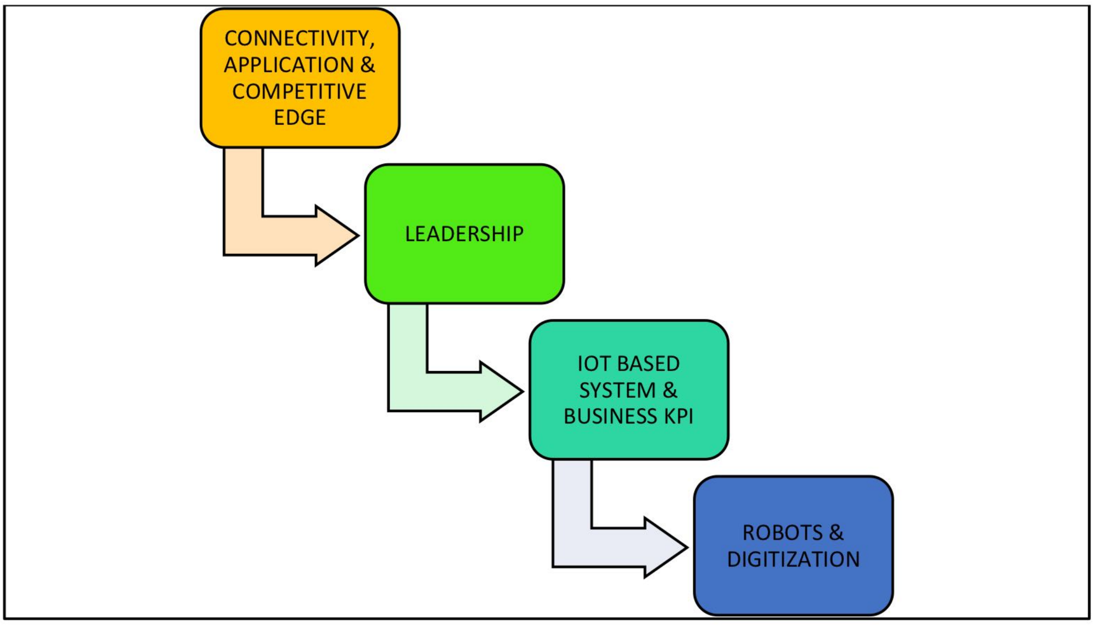
Table 3.46 Level-8 Partitioning of the Impediments

	IMPEDIMENTS				
LEVEL 8 PARTITIONI NG	FACTOR S	REACHABILI TY SET	ANTECEDE NT SET	INTERSECTI ON SET	LEVE L
	1				
	2				
	3				
	4	4	4	4	VIII
	5				
	6				
	7				
	8				
	9				

Table 3.47 Final Reachability matrix for Catalysts

	CATALYST				
	FACTORS	REACHABILITY SET	ANTECEDENT SET	INTERSECTION SET	LEVEL
Leadership	1	1,3,5,7,8	1,5	1	II
Connectivity	2	2,3,4,6,7	2	2	I
Digitization	3	3,6,7	1,2,3,4,5,6,7,8	3	IV
IOT based system	4	2,3,4,7	2,4,6	4	III
Business KPI	5	1,3,5,8	1,5	5	III
Application	6	3,4,6	2,3,6,7	3	I
ROBOTS	7	3,4,6,7	1,2,3,4,7	7	IV
Competitive edge	8	3,8	1,5,8	8	I

Figure- 3.9 – Final flowchart for Catalysts

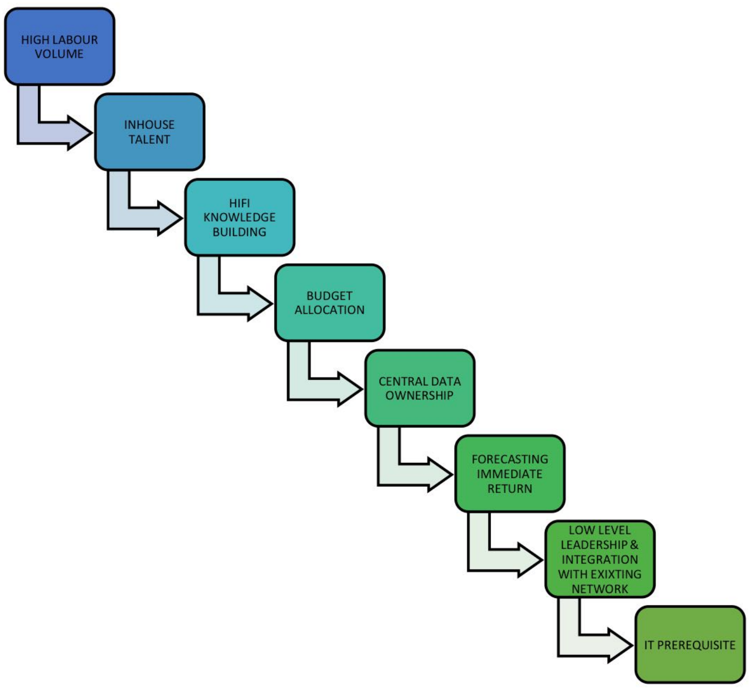


Source: Singh et al. (2024)

Table3.48 Final Reachability matrix for impediments

IMPEDIMENTS	FACTORS	REACHABILITY SET	ANTECEDENT SET	INTERSECTION SET	LEVEL
Forecasting immediate return	1	1,2,3,6,7,9	1,7,8,9	1	VI
Inhouse talent	2	2,5	1,2,4,6,7,8, 9	2	II
Low level leadership	3	1,3,6,7,9	1,3,4,6,7	3	VII
IT prerequisite	4	2,3,4,6	4,6,7	4	VIII
High labour volume	5	5,8	5	5	I
Integration with existing networking	6	2,3,6,8	1,3,4,6,7	6	VII
Central Data ownership	7	1,2,4,6,7,8	3,7	7	V
High-fi level knowledge building	8	1,2,8	2,5,6,7,8,9	8	III
Budget allocation	9	1,2,8,9	1,3,8,9	9	IV

Figure3.10 Final flowchart for Impediments



Source: Singh et al. (2024)

3.12 Conclusion

The research methodology presented in this chapter provides a comprehensive and systematic approach to studying the implementation of Industry 4.0 in production planning and control within the Indian automobile industry. The combined use of Fuzzy Delphi, Fuzzy COPRAS, Fuzzy BWM, and Fuzzy ISM ensures that the study captures the complexity and interdependencies of the various factors influencing Industry 4.0 adoption. Sensitivity analysis enhances the reliability of the findings, ensuring that conclusions remain valid under different scenarios and conditions.

Chapter 4

RESULTS & DISCUSSION

Chapter Overview

This chapter provide the results of each methodologies adopted and discussion about their relevance towards solving the problem. This chapter gives the result for all the objectives identified followed by the validation result of one case which is taken from one OEM for one aggregate. This chapter proves the advantages of implementation of Industry4.0 for Production planning and control.

4.1 Introduction

To implement Industry 4.0 in production planning and control (PPC), this study aimed to develop a framework that industries can utilize as a starting point for their Industry 4.0 journey. Through detailed analysis and the application of a multi-criteria decision-making (MCDM) approach, the study ranked the most critical readiness factors. Initially, 182 readiness factors were identified for the Delphi study, which were refined to 21 key factors after several Delphi study rounds. The Fuzzy COPRAS technique was employed to rank these readiness factors based on inputs from 18 industry experts across various automotive organizations (Singh, 2024a; Singh et al., 2024b).

After thorough analysis, it was concluded that the **digitization of the supply chain** should be the top priority for implementing Industry 4.0 in PPC. The second-ranked factor was the **availability of Industrial Internet of Things (IIoT)** to enable digital data collection through tools like scanners and barcode readers, supporting supply chain digitization. The third priority was the **availability of hardware for data storage**, such as clouds, hard drives, and supercomputers, for connectivity between IIoT and the digital supply chain.

The fourth rank was assigned to **IT integration software** to manage data from the digital supply chain, including inputs from multiple locations and components. Fifth on the list was a **collaboration network** among parent, Tier 1, and Tier 2 industries for timely feedback and feedforward mechanisms. The sixth rank went to **data-driven services**, facilitating schedule changes, design updates, delivery feedback, and interlinked purchase orders based on vehicle production priorities.

The seventh factor emphasized **evaluating the competencies** required to transition to digital platforms, ensuring real-time processing and supply chain adjustments based on constraints. The eighth rank highlighted **Internet and Communication Technology (ICT)** to support machines, production lines, dispatch systems, and related processes. **Upgrading data storage capacity** ranked ninth, focusing on the storage and analysis of collected data.

The tenth priority was the **availability of an IIoT platform** at each step of the production process at parent, Tier 1, and Tier 2 plants. Ranked eleventh was a **dedicated change management team** to oversee planning and execution of Industry 4.0 projects. The twelfth factor emphasized **skill development** for employees involved in Industry 4.0 applications in PPC, while the thirteenth rank focused on **collaborating with external experts** to enhance skills and update technologies.

The fourteenth priority was the **digitization of the entire organization**, including parent plants and vendors, to capture comprehensive data for Industry 4.0 implementation. Ranked fifteenth was the **development of a roadmap strategy** with Gantt charts to track implementation timelines and success rates. **Leadership involvement**, ranked sixteenth, was critical for driving digital transformation projects.

Seventeenth on the list was the **inclusion of Industry 4.0 KPIs** for top management to monitor progress. The development of a **long-term strategy** for Industry 4.0 ranked eighteenth, followed by the **calculation of costs for technology setup** to support future projects, which ranked nineteenth. The twentieth rank was assigned to **financial planning for technology maintenance**, ensuring sustainability. Finally, the twenty-first rank focused on **evaluating the total project cost versus benefits** to perform breakeven analysis and present a business case to senior management (Singh, 2024a; Singh et al., 2024b).

4.2 Result- Objective 1

Table 4.1 Ranking of Readiness Factors

Readiness Factors	RANK
Evaluation of digitization of supply chain in industry for implementation of Industry 4.0 in PPC	1
Requirement of Industrial Internet of Things (IIoT) in Industry for implementation of INDUSTRY 4.0 in PPC	2
Machine communication- Hardware component for implementation of INDUSTRY 4.0 in PPC	3
Availability of IT Integration software for implementation of INDUSTRY 4.0 in PPC	4
Requirement of Collaboration Network in industry for implementation of Industry 4.0 in PPC	5
Requirement of Data Driven services in industry for implementation of INDUSTRY 4.0 in PPC	6
Digital Capabilities of the industry for implementation of INDUSTRY 4.0 in PPC	7
Availability of Internet and Communication Technology in industry for implementation of INDUSTRY 4.0 in PPC	8
Capacity of Data Storage of the industry for implementation of INDUSTRY 4.0 in PPC	9
Requirement of IOT platforms for implementation of INDUSTRY 4.0 in PPC	10
Presence of change management in industry for implementation of Industry 4.0 in PPC	11
Requirement of Knowledge about technology in industry for implementation of INDUSTRY 4.0 in PPC	12
Requirement of technology Proficiency in industry for implementation of Industry 4.0 in PPC	13
Level of digitization of the organization for implementation of INDUSTRY 4.0 in PPC	14
Requirement of Road map Strategy in industry for implementation of Industry 4.0 in PPC	15
Availability of Leadership in industry for implementation of Industry 4.0 in PPC	16

Requirement of Top management involvement and commitment in industry for implementation of Industry 4.0 in PPC	17
Presence of long-term strategy in industry for implementation of Industry 4.0 in PPC	18
Requirement of Calculating the Cost of technology for implementation of Industry 4.0 in PPC	19
Requirement of Financial aid given for implementation of Industry 4.0 in PPC	20
Requirement of calculating the Implementation cost for implementation of Industry 4.0 in PPC	21

The Table represents the final readiness factors ranking based on the decision maker's responses and Fuzzy CoPrAs calculation. These ranks are the final output of the Fuzzy CoPrAs calculation which will decide the steps which are most important and mandatory for implementation of Industry 4.0 in Production Planning and Control.

4.3 Result- Objective 2 & 3

According to the statistical analysis conducted, based on responses from various participants, leadership emerged as the most critical and impactful catalyst for initiating Industry 4.0 implementation. It was also observed that industries should avoid focusing solely on forecasting immediate returns from the investments made in Industry 4.0 technologies. Using this analysis, catalysts can be ranked, with the most significant or effective being assigned Rank 1 and the least effective as Rank 7.

Industries should prioritize establishing strong, top-down leadership, as they play a pivotal role in driving the successful implementation of Industry 4.0 in production planning and control (PPC). Connecting vendors, dealers, and shops through digital platforms and the Internet should also be a focus area, as it marks the initial phase (Application) of Industry 4.0 adoption in PPC.

Additionally, industries should capitalize on easily accessible technologies, such as integrating robots through the Internet of Things (IoT). Monitoring external competition to understand the application of technology in rival firms and the resulting advantages can guide industries in upgrading their own technology to achieve similar or greater benefits.

Table 4.2 Ranking of top catalysts

LIST OF CATALYSTS	RANK
Leadership	1
Connectivity	2
Digitization	3
IOT based system	3
Business KPI	4
Application	5
ROBOTS	5
Competitive edge	6
Technology upgradation	7

For impediments, the most significant challenges are ranked as 1, with the least significant ranked as 7. This highlight key areas industries should avoid during the implementation of Industry 4.0 in production planning and control (PPC). Industries are advised not to focus solely on forecasting immediate returns and should refrain from relying entirely on in-house talent for the implementation process. Instead, they should seek assistance from technical experts, particularly in the initial stages of implementation.

Organizations should avoid low-level leadership for managing Industry 4.0 projects related to PPC. Furthermore, industries should not delay these projects while waiting for IT prerequisites to be fully established. Hiring excessive labor during the initial phase of Industry 4.0 implementation is also discouraged. Integrating Industry 4.0 into existing network systems without adequate preparation may disrupt routine operations and should be approached cautiously.

Additionally, centralized ownership of data is not recommended, as Industry 4.0 thrives on data connectivity. Fragmented data ownership allows for faster and more effective debugging. Industries should avoid over-investing in advanced knowledge development for workers at the early stages of implementation. Lastly, repeatedly seeking budget approvals for Industry 4.0 projects could dilute the core benefits and delay the overall progress of implementation.

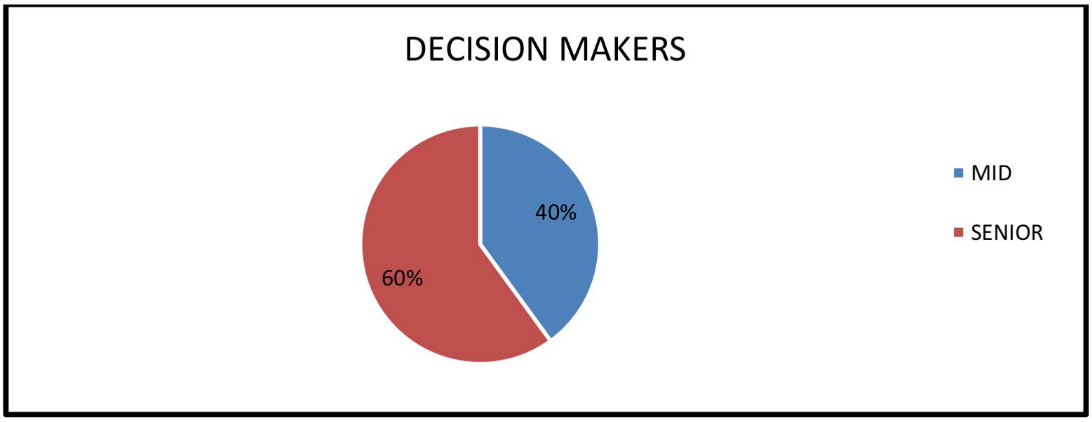
Table 4.3 Ranking of top Impediments

LIST OF IMPEDIMENTS	RANK
Forecasting immediate return	1
Inhouse talent	2
Low level leadership	3
IT prerequisite	3
High labour volume	4
Integration with existing networking	5
Central Data ownership	6
High-fi level knowledge building	6
Budget allocation	7

4.4 Result- Objective 4

With the help of Fuzzy ISM method and 20 decision makers from top automobile companies, below are the results of the analysis done to find out the priority order flow chart with level partitioning.

Figure 4.1 Decision makers for Fuzzy ISM



Source: Singh et al. (2024)

Table 4.4 Final Reachability matrix for Catalysts

CATALYST	FACTORS	REACHABILITY SET	ANTECEDENT SET	INTERSECTION SET	LEVEL
Leadership	1	1,3,5,7,8	1,5	1	II
Connectivity	2	2,3,4,6,7	2	2	I
Digitization	3	3,6,7	1,2,3,4,5,6,7,8	3	IV
IOT based system	4	2,3,4,7	2,4,6	4	III
Business KPI	5	1,3,5,8	1,5	5	III
Application	6	3,4,6	2,3,6,7	3	I
ROBOTS	7	3,4,6,7	1,2,3,4,7	7	IV
Competitive edge	8	3,8	1,5,8	8	I

Table 4.5 Final Reachability matrix for impediments

IMPEDIMENTS	FACTORS	REACHABILITY SET	ANTECEDENT SET	INTERSECTION SET	LEVEL
Forecasting immediate return	1	1,2,3,6,7,9	1,7,8,9	1	VI
In-house talent	2	2,5	1,2,4,6,7,8,9	2	II
Low level leadership	3	1,3,6,7,9	1,3,4,6,7	3	VII
IT prerequisite	4	2,3,4,6	4,6,7	4	VIII
High labour volume	5	5,8	5	5	I
Integration with existing networking	6	2,3,6,8	1,3,4,6,7	6	VII
Central Data ownership	7	1,2,4,6,7,8	3,7	7	V

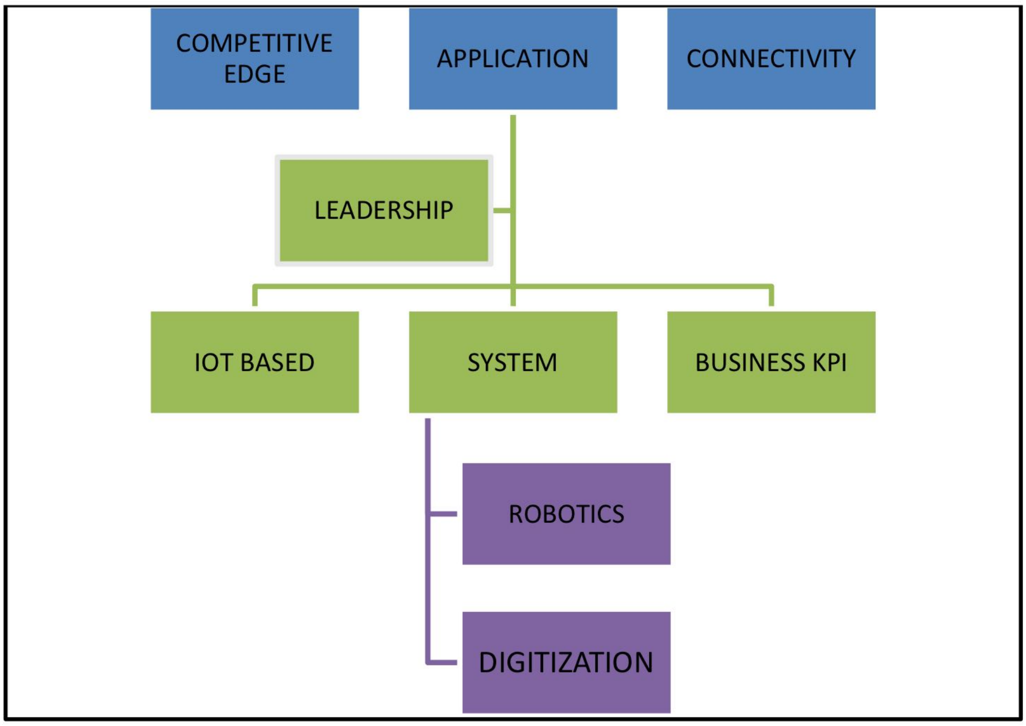
High-fi level knowledge building	8	1,2,8	2,5,6,7,8,9	8	III
Budget allocation	9	1,2,8,9	1,3,8,9	9	IV

As per analysis, Connectivity, application and Competition among market leader is the main parameter which every industry should focus upon for implementation of Industry 4.0 in their industry followed by a good and strong leadership to lead the team in right direction with setting up targets and KPI for IOT based system and Robots with digitization.

In parallel any industry should not get involved in creating high labour volume immediately or start developing inhouse talent with Hi-fi level knowledge to suit the technology without understanding its application. At initial stage budget and immediate return should not bother any industry.

4.5 Contextual relationship among catalysts

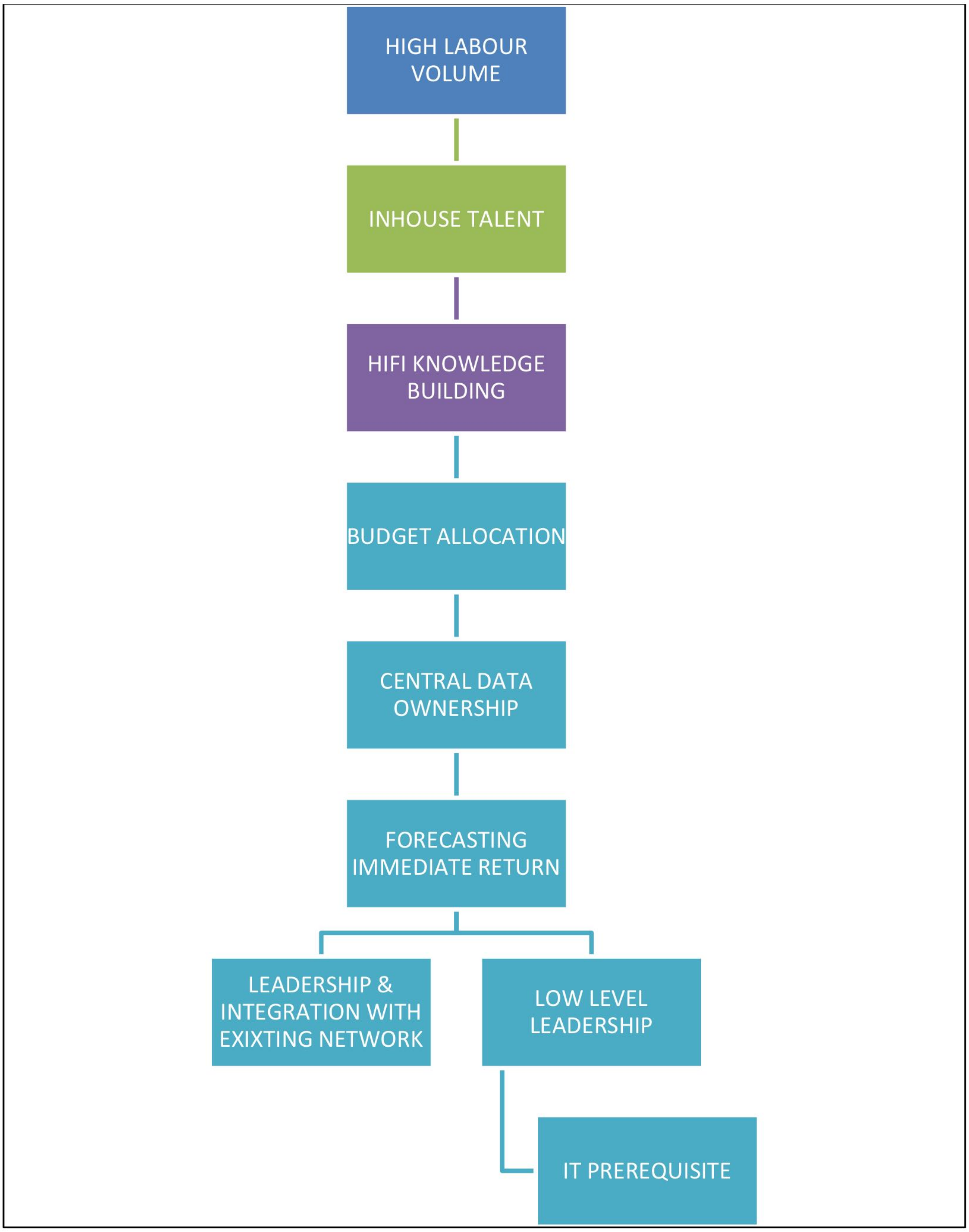
Figure 4.2 Contextual relationship among catalysts



Source: Singh et al. (2024)

4.6 Contextual relationship among impediments

Figure 4.3 Contextual relationship among Impediments



Source: Singh et al. (2024)

4.7 Contributions

This section outlines the key contributions of this research to the theoretical framework, research methodology, and practical management strategies for implementing Industry 4.0 in production planning and control (PPC) within the Indian automobile industry. The contributions are categorized into three parts: theoretical, research, and managerial.

4.7.1 Theoretical Contribution

This research offers significant theoretical contributions by enhancing the existing frameworks on Industry 4.0 adoption, specifically in the context of production planning and control.

Framework for Industry 4.0 Readiness: The study proposes a comprehensive framework for assessing the readiness of automobile industries for Industry 4.0 adoption in PPC. While many models focus on the technological aspects, this research incorporates additional dimensions such as organizational culture, human resources, and financial investment, offering a holistic approach to readiness.

Insights into Enablers and Barriers: By using Fuzzy Delphi and Fuzzy ISM methods, this research identifies the key enablers and barriers to implementing Industry 4.0, while also analysing the relationships between these factors. This adds a theoretical depth to the understanding of how various enablers interact and how barriers can be overcome, contributing to the broader knowledge of digital transformation in PPC.

Adaptable Framework for Other Industries: Although focused on the automobile industry, the framework and findings can be adapted to other industries. The study derives factors that are directly or indirectly related to Industry 4.0 implementation, providing guidance for industries beyond the automotive sector to start their journey toward adopting these technologies.

4.7.2 Research Contribution

This research makes notable methodological contributions by employing advanced decision-making techniques and providing a clear pathway for future studies.

Innovative Methodology for Industry 4.0 Adoption: The combination of Fuzzy Delphi, Fuzzy COPRAS, Fuzzy Best-Worst Method (BWM), and Fuzzy ISM provides a novel methodological approach for understanding complex decision-making in Industry 4.0 adoption. This integrated use of fuzzy logic and multi-criteria decision-making techniques allows for a more accurate analysis of expert opinions and uncertainties.

Real-World Application: The research is based on a pilot project from one of the leading automobile companies in India. This real-world application of Industry 4.0 in PPC makes the research more relevant and actionable for other companies, especially those in the Indian automobile industry and their Tier 1, 2, and 3 suppliers. The insights derived can serve as a benchmark for similar studies across different industries and sectors.

Step-by-Step Guidelines for Implementation: The study contributes to future research by providing step-by-step guidelines for companies looking to begin their Industry 4.0 journey in production planning and control. These guidelines, derived from systematic analysis, can serve as a foundation for further academic exploration and practical application in diverse industries, both within and outside the automotive sector.

4.7.3 Managerial Contribution

The managerial contributions of this research are focused on providing practical tools and insights for managers, enabling them to effectively implement Industry 4.0 in their PPC processes.

Strategic Roadmap for Industry 4.0 Implementation: This research offers a comprehensive roadmap for managers in the automobile industry, as well as their Tier 1, 2, and 3 suppliers, to implement Industry 4.0 technologies in PPC. It provides clear guidance on the readiness factors, enablers, and barriers to focus on, helping managers make informed decisions when embarking on digital transformation initiatives.

Practical Steps for "Connected Organization": The study emphasizes the concept of a "Connected Organization," where all stakeholders within the supply chain, from the parent company to Tier 1, 2, and 3 suppliers, are aligned with the production plan and can adapt their operations in real-time. This ensures seamless coordination across the supply chain, enabling industries to achieve "Just in Time" (JIT) production and stay updated with the latest supply chain demands.

Broader Applicability for Non-Automotive Sectors: Although the study is cantered on the automobile industry, its findings and recommendations can be applied to any industry looking to implement Industry 4.0 in their PPC and supply chain management (SCM) processes. This universal approach makes the research valuable for a wide range of industries seeking to enhance efficiency, reduce lead times, and improve resource allocation through digital transformation.

In conclusion, this research offers valuable contributions that will aid the automobile industry, and other sectors, in their transition to Industry 4.0. The study provides a solid theoretical foundation, innovative research methodology, and practical, actionable insights for managers to improve their production planning and supply chain management, ensuring better alignment, real-time responsiveness, and overall operational efficiency

4.8 Quantitative Method to Validate effect of implementation of Industry 4.0 in PPC

To validate the result of implementing Industry 4.0 in Production Planning and Control, we need to have an experimental design with hypothesis as “The implementation of Industry 4.0 has no significance in the industry on the key supply chain performance measure with respect to Inventory”.

For analysis, only two industries inventory analysis is considered in terms of quantity. Industries name is kept confidential due to its code of conduct. Both the industries are OEM and Only Axle Factory of their industry is considered for hypothesis checking through t test.

Rear Axle is comprises of

1. Casting parts
2. Forging parts
3. Sheet metal stamping parts

The data is collected for the specific parts of Casting, Forging and Sheet metal stampings for Vendor 1 and Vendor 2.

Both the data of inventory with and without Industry 4.0 implementation will be tabulated for both the Vendor sets having different prices and different locations.

VENDOR SET-1 AND 2 WITHOUT INDUSTRY 4.0 IMPLEMENTATION

Table 4.6 Vendor sets for Inventory calculation

PARTS	**CLASSIFICATION**	**SUPPLIER1**	**SOB (Share of Business**	**PRICE @ SUPPLIER1**	**DAILY REQUIREMENT**
Carrier Housing	C	MAVAL FOUNDARY	60%	6000	300
Rear Hub	C	MAVAL FOUNDARY	20%	2314	600
Case cover	C	MAVAL FOUNDARY	50%	1173	300
SBA Mtg Bracket	C	MAVAL FOUNDARY	30%	650	600
Crown Wheel	F	ECHJAY FORGINGS	70%	2200	300
Pinion	F	ECHJAY FORGINGS	70%	970	300
Saddle	F	ECHJAY FORGINGS	20%	250	600
RA Beam	S	RSB INDUSTRIES	80%	13500	300
RA Brake pressure plate	S	BRAKES INDIA	60%	850	600
PARTS	**CLASSIFICATION**	**SUPPLIER2**	**SOB (Share of Business**	**PRICE @ SUPPLIER1**	**DAILY REQUIREMENT**
Carrier Housing	C	MUTHA ENGG	40%	6700	300
Rear Hub	C	MUTHA ENGG	80%	2457	600
Case cover	C	MUTHA ENGG	50%	1456	300
SBA Mtg Bracket	C	MUTHA ENGG	70%	670	600
Crown Wheel	F	ANC	30%	2750	300
Pinion	F	ANC	30%	1035	300
Saddle	F	ANC	80%	250	600
RA Beam	S	AXLE INDIA	20%	14200	300
RA Brake pressure plate	S	MERITOR	40%	1045	600

Table 4.7 Minimum Inventory in plant for supplier set1 and supplier set2

PARTS	SUPPLIER1	SOURCE KM	DAYS IN TRANSIT	INVENTORY ON WHEELS	MINIMUM INVENTORY IN PLANT (NOS)
Carrier Housing	MAVAL FOUNDARY	30	1	0	180
Rear Hub	MAVAL FOUNDARY	30	1	0	120
Case cover	MAVAL FOUNDARY.	30	1	0	150
SBA Mtg Bracket	MAVAL FOUNDARY	30	1	0	180
Crown Wheel	ECHJAY FORGINGS	152	1	0	210
Pinion	ECHJAY FORGINGS	152	1	0	210
Saddle	ECHJAY FORGINGS	152	1	0	120
RA Beam	RSB INDUSTRIES	2200	5	1200	240
RA Brake pressure plate	BRAKES INDIA	1700	5	2400	360
PARTS	SUPPLIER2	SOURCE KM			
Carrier Housing	MUTHA ENGG	800	3	600	120
Rear Hub	MUTHA ENGG	800	3	1200	480
Case cover	MUTHA ENGG	800	3	600	150
SBA Mtg Bracket	MUTHA ENGG	800	3	1200	420
Crown Wheel	ANC	22	1	0	90
Pinion	ANC	22	1	0	90
Saddle	ANC	22	1	0	480
RA Beam	AXLE INDIA	1152	4	900	60
RA Brake pressure plate	MERITOR	912	4	1800	240

Table 4.8 Inventory at Supplier end

PARTS	SUPPLIER1	MINIMUM INVENTORY IN PLANT (COST)	INVENTORY ON WHEELS (COST)	TOTAL OPERATING INVENTORY	INVENTORY @ SUPPLIER (NOS)
Carrier Housing	MAVAL FOUNDARY	648000	0	₹ 6,48,000	500

Rear Hub	MAVAL FOUNDARY	55536	0	₹ 55,536	500
Case cover	MAVAL FOUNDARY	87975	0	₹ 87,975	500
SBA Mtg Bracket	MAVAL FOUNDARY	35100	0	₹ 35,100	500
Crown Wheel	ECHJAY FORGINGS	323400	0	₹ 3,23,400	2000
Pinion	ECHJAY FORGINGS	142590	0	₹ 1,42,590	2000
Saddle	ECHJAY FORGINGS	6000	0	₹ 6,000	2000
RA Beam	RSB INDUSTRIE S	2592000	12960000	₹ 1,55,52,000	1000
RA Brake pressure plate	BRAKES INDIA	183600	1224000	₹ 14,07,600	1000
PARTS	SUPPLIER2				
Carrier Housing	MUTHA ENGG	321600	1608000	₹ 19,29,600	500
Rear Hub	MUTHA ENGG	943488	2358720	₹ 33,02,208	500
Case cover	MUTHA ENGG	109200	436800	₹ 5,46,000	500
SBA Mtg Bracket	MUTHA ENGG	196980	562800	₹ 7,59,780	500
Crown Wheel	ANC	74250	0	₹ 74,250	2000
Pinion	ANC	27945	0	₹ 27,945	2000
Saddle	ANC	96000	0	₹ 96,000	2000
RA Beam	AXLE INDIA	170400	2556000	₹ 27,26,400	1000
RA Brake pressure plate	MERITOR	100320	752400	₹ 8,52,720	1000

Table 4.9 Operating cost for Supplier set1 and supplier set2

PARTS	SUPPLIER1	INVENTORY @ SUPPLIER (COST)	OPERATING RAW MATERIAL (NOS)	OPERATING RAW MATERIAL (COST)
Carrier Housing	MAVAL FOUNDARY	₹ 30,00,000	4500	₹ 1,62,00,000
Rear Hub	MAVAL FOUNDARY	₹ 11,57,000	3000	₹ 41,65,200
Case cover	MAVAL FOUNDARY	₹ 5,86,500	3750	₹ 26,39,250
SBA Mtg Bracket	MAVAL FOUNDARY	₹ 3,25,000	4500	₹ 17,55,000
Crown Wheel	ECHJAY FORGINGS	₹ 44,00,000	5250	₹ 69,30,000

Pinion	ECHJAY FORGINGS	₹ 19,40,000	5250	₹ 30,55,500
Saddle	ECHJAY FORGINGS	₹ 5,00,000	3000	₹ 4,50,000
RA Beam	RSB INDUSTRIES	₹ 1,35,00,000	6000	₹ 4,86,00,000
RA Brake pressure plate	BRAKES INDIA	₹ 8,50,000	9000	₹ 45,90,000
PARTS	SUPPLIER2			
Carrier Housing	MUTHA ENGG	₹ 33,50,000	3000	₹ 1,20,60,000
Rear Hub	MUTHA ENGG	₹ 12,28,500	12000	₹ 1,76,90,400
Case cover	MUTHA ENGG	₹ 7,28,000	3750	₹ 32,76,000
SBA Mtg Bracket	MUTHA ENGG	₹ 3,35,000	10500	₹ 42,21,000
Crown Wheel	ANC	₹ 55,00,000	2250	₹ 37,12,500
Pinion	ANC	₹ 20,70,000	2250	₹ 13,97,250
Saddle	ANC	₹ 5,00,000	12000	₹ 18,00,000
RA Beam	AXLE INDIA	₹ 1,42,00,000	1500	₹ 1,27,80,000
RA Brake pressure plate	MERITOR	₹ 10,45,000	6000	₹ 37,62,000

AFTER IMPLEMENTATION OF INDUSTRY 4.0

Table 4.10 Inventory calculation with Industry 4.0

PARTS	CLASS IFICA TION	SUPPLIER1	SOB (Share of Business	PRICE @ SUPPLIER1	DAILY REQUIREMENT
Carrier Housing	C	MAVAL FOUNDARY	60%	6000	300
Rear Hub	C	MAVAL FOUNDARY	20%	2314	600
Case cover	C	MAVAL FOUNDARY	50%	1173	300
SBA Mtg Bracket	C	MAVAL FOUNDARY	30%	650	600
Crown Wheel	F	ECHJAY FORGINGS	70%	2200	300
Pinion	F	ECHJAY FORGINGS	70%	970	300
Saddle	F	ECHJAY FORGINGS	20%	250	600
RA Beam	S	RSB INDUSTRIES	80%	13500	300
RA Brake pressure plate	S	BRAKES INDIA	60%	850	600

PARTS	CLASS IFICAT ION	SUPPLIER2		PRICE @ SUPPLIER2	
Carrier Housing	C	MUTHA ENGG	40%	6700	300
Rear Hub	C	MUTHA ENGG	80%	2457	600
Case cover	C	MUTHA ENGG	50%	1456	300
SBA Mtg Bracket	C	MUTHA ENGG	70%	670	600
Crown Wheel	F	ANC	30%	2750	300
Pinion	F	ANC	30%	1035	300
Saddle	F	ANC	80%	250	600
RA Beam	S	AXLE INDIA	20%	14200	300
RA Brake pressure plate	S	MERITOR	40%	1045	600

Table 4.11 Minimum plant inventory at plant after Industry 4.0 implementation

PARTS	**SUPPLIER1**	**SOURCE KM**	**DAYS IN TRANSIT**	**INVENTORY ON WHEELS**	**MINIMUM INVENTORY IN PLANT (NOS)**
Carrier Housing	MAVAL FOUNDARY	30	1	0	180
Rear Hub	MAVAL FOUNDARY	30	1	0	120
Case cover	MAVAL FOUNDARY	30	1	0	150
SBA Mtg Bracket	MAVAL FOUNDARY	30	1	0	180
Crown Wheel	ECHJAY FORGINGS	152	1	0	210
Pinion	ECHJAY FORGINGS	152	1	0	210
Saddle	ECHJAY FORGINGS	152	1	0	120
RA Beam	RSB INDUSTRIES	2200	5	1200	240
RA Brake pressure plate	BRAKES INDIA	1700	5	2400	360
PARTS	SUPPLIER2	SOURCE KM			
Carrier Housing	MUTHA ENGG	800	3	600	120
Rear Hub	MUTHA ENGG	800	3	1200	480
Case cover	MUTHA ENGG	800	3	600	150
SBA Mtg Bracket	MUTHA ENGG	800	3	1200	420

Crown Wheel	ANC	22	1	0	90
Pinion	ANC	22	1	0	90
Saddle	ANC	22	1	0	480
RA Beam	AXLE INDIA	1152	4	900	60
RA Brake pressure plate	MERITOR	912	4	1800	240

Table 4.12 Total Operating cost for supplier after industry 4.0 implementation

PARTS	SUPPLIER1	MINIMUM INVENTORY IN PLANT (COST)	INVENTORY ON WHEELS (COST)	TOTAL OPERATING INVENTORY
Carrier Housing	MAVAL FOUNDARY	648000	0	₹ 6,48,000
Rear Hub	MAVAL FOUNDARY	55536	0	₹ 55,536
Case cover	MAVAL FOUNDARY	87975	0	₹ 87,975
SBA Mtg Bracket	MAVAL FOUNDARY	35100	0	₹ 35,100
Crown Wheel	ECHJAY FORGINGS	323400	0	₹ 3,23,400
Pinion	ECHJAY FORGINGS	142590	0	₹ 1,42,590
Saddle	ECHJAY FORGINGS	6000	0	₹ 6,000
RA Beam	RSB INDUSTRIES	2592000	12960000	₹ 1,55,52,000
RA Brake pressure plate	BRAKES INDIA	183600	1224000	₹ 14,07,600
PARTS	SUPPLIER2			
Carrier Housing	MUTHA ENGG	321600	1608000	₹ 19,29,600
Rear Hub	MUTHA ENGG	943488	2358720	₹ 33,02,208
Case cover	MUTHA ENGG	109200	436800	₹ 5,46,000
SBA Mtg Bracket	MUTHA ENGG	196980	562800	₹ 7,59,780
Crown Wheel	ANC	74250	0	₹ 74,250
Pinion	ANC	27945	0	₹ 27,945
Saddle	ANC	96000	0	₹ 96,000
RA Beam	AXLE INDIA	170400	2556000	₹ 27,26,400
RA Brake pressure plate	MERITOR	100320	752400	₹ 8,52,720

Table 4.13 Operating cost of suppliers after implementation of Industry 4.0 in PPC

PARTS	**SUPPLIER1**	**INVENTORY @ SUPPLIER (NOS)**	**INVENTORY @ SUPPLIER (COST)**	**OPERATING RAW MATERIAL (NOS)**	**OPERATING RAW MATERIAL (COST)**
Carrier Housing	MAVAL FOUNDARY	300	₹ 18,00,000	900	₹ 32,40,000
Rear Hub	MAVAL FOUNDARY	600	₹ 13,88,400	600	₹ 8,33,040
Case cover	MAVAL FOUNDARY	300	₹ 3,51,900	750	₹ 5,27,850
SBA Mtg Bracket	MAVAL FOUNDARY	600	₹ 3,90,000	900	₹ 3,51,000
Crown Wheel	ECHJAY FORGINGS	300	₹ 6,60,000	1050	₹ 13,86,000
Pinion	ECHJAY FORGINGS	300	₹ 2,91,000	1050	₹ 6,11,100
Saddle	ECHJAY FORGINGS	600	₹ 1,50,000	600	₹ 90,000
RA Beam	RSB INDUSTRIES	300	₹ 40,50,000	1200	₹ 97,20,000
RA Brake pressure plate	BRAKES INDIA	600	₹ 5,10,000	1800	₹ 9,18,000
PARTS	SUPPLIER2				
Carrier Housing	MUTHA ENGG	300	₹ 20,10,000	600	₹ 24,12,000
Rear Hub	MUTHA ENGG	600	₹ 14,74,200	2400	₹ 35,38,080
Case cover	MUTHA ENGG	300	₹ 4,36,800	750	₹ 6,55,200
SBA Mtg Bracket	MUTHA ENGG	600	₹ 4,02,000	2100	₹ 8,44,200
Crown Wheel	ANC	300	₹ 8,25,000	450	₹ 7,42,500
Pinion	ANC	300	₹ 3,10,500	450	₹ 2,79,450
Saddle	ANC	600	₹ 1,50,000	2400	₹ 3,60,000
RA Beam	AXLE INDIA	300	₹ 42,60,000	300	₹ 25,56,000
RA Brake pressure plate	MERITOR	600	₹ 6,27,000	1200	₹ 7,52,400

For calculating the 2 vendor sets against with and without implementing Industry 4.0, below sets are required to calculate t value

Table 4.14 Inventory table before and After

PARTS	**CLASSIFICATION**	**SUPPLIER1**	**PAST TOTAL INVENTORY**	**TOTAL INVENTORY INDUSTRY 4.0**
Carrier Housing	C	MAVAL FOUNDARY	19848000	5688000
Rear Hub	C	MAVAL FOUNDARY	5377736	2276976

Case cover	C	MAVAL FOUNDARY	3313725	967725
SBA Mtg Bracket	C	MAVAL FOUNDARY	2115100	776100
Crown Wheel	F	ECHJAY FORGINGS	11653400	2369400
Pinion	F	ECHJAY FORGINGS	5138090	1044690
Saddle	F	ECHJAY FORGINGS	956000	246000
RA Beam	S	RSB INDUSTRIES	77652000	29322000
RA Brake pressure plate	S	BRAKES INDIA	6847600	2835600
PARTS	**CLASSIFICATION**	**SUPPLIER2**	**PAST TOTAL INVENTORY**	**TOTAL INVENTORY INDUSTRY 4.0**
Carrier Housing	C	MUTHA ENGG	17339600	6351600
Rear Hub	C	MUTHA ENGG	22221108	8314488
Case cover	C	MUTHA ENGG	4550000	1638000
SBA Mtg Bracket	C	MUTHA ENGG	5315780	2005980
Crown Wheel	F	ANC	9286750	1641750
Pinion	F	ANC	3495195	617895
Saddle	F	ANC	2396000	606000
RA Beam	S	AXLE INDIA	29706400	9542400
RA Brake pressure plate	S	MERITOR	5659720	2232120

To calculate value of t, below are the formulas

$$t= \frac{A1-\bar{A}1}{S\sqrt{(\frac{1}{n1}+\frac{1}{n2})}}$$

$$S= \frac{(n1-1)s1^2+(n2-1)s2^2}{n1+n2-2}$$

$$s=\sqrt{\frac{\sum(An-\bar{A}n)^2}{n-1}}$$

$$df= n1+n2-2$$

where;

A and Ā1 are the sample means of the two groups being compared

$n1$ and $n2$ are the sample sizes of the two groups being compared

S is the pooled sample variance, s1 and s2 are the sample variance of the each group

df is the degrees of freedom

Table 4.15 Critical values of t

Critical values of *t* for two-tailed tests

Significance level (α)

Degrees of freedom *(df)*	.2	.15	.1	.05	.025	.01	.005	.001
1	3.078	4.165	6.314	12.706	25.452	63.657	127.321	636.619
2	1.886	2.282	2.920	4.303	6.205	9.925	14.089	31.599
3	1.638	1.924	2.353	3.182	4.177	5.841	7.453	12.924
4	1.533	1.778	2.132	2.776	3.495	4.604	5.598	8.610
5	1.476	1.699	2.015	2.571	3.163	4.032	4.773	6.869
6	1.440	1.650	1.943	2.447	2.969	3.707	4.317	5.959
7	1.415	1.617	1.895	2.365	2.841	3.499	4.029	5.408
8	1.397	1.592	1.860	2.306	2.752	3.355	3.833	5.041
9	1.383	1.574	1.833	2.262	2.685	3.250	3.690	4.781
10	1.372	1.559	1.812	2.228	2.634	3.169	3.581	4.587
11	1.363	1.548	1.796	2.201	2.593	3.106	3.497	4.437
12	1.356	1.538	1.782	2.179	2.560	3.055	3.428	4.318
13	1.350	1.530	1.771	2.160	2.533	3.012	3.372	4.221
14	1.345	1.523	1.761	2.145	2.510	2.977	3.326	4.140
15	1.341	1.517	1.753	2.131	2.490	2.947	3.286	4.073
16	1.337	1.512	1.746	2.120	2.473	2.921	3.252	4.015
17	1.333	1.508	1.740	2.110	2.458	2.898	3.222	3.965
18	1.330	1.504	1.734	2.101	2.445	2.878	3.197	3.922
19	1.328	1.500	1.729	2.093	2.433	2.861	3.174	3.883
20	1.325	1.497	1.725	2.086	2.423	2.845	3.153	3.850
21	1.323	1.494	1.721	2.080	2.414	2.831	3.135	3.819
22	1.321	1.492	1.717	2.074	2.405	2.819	3.119	3.792
23	1.319	1.489	1.714	2.069	2.398	2.807	3.104	3.768
24	1.318	1.487	1.711	2.064	2.391	2.797	3.091	3.745
25	1.316	1.485	1.708	2.060	2.385	2.787	3.078	3.725
26	1.315	1.483	1.706	2.056	2.379	2.779	3.067	3.707
27	1.314	1.482	1.703	2.052	2.373	2.771	3.057	3.690
28	1.313	1.480	1.701	2.048	2.368	2.763	3.047	3.674
29	1.311	1.479	1.699	2.045	2.364	2.756	3.038	3.659
30	1.310	1.477	1.697	2.042	2.360	2.750	3.030	3.646
40	1.303	1.468	1.684	2.021	2.329	2.704	2.971	3.551
50	1.299	1.462	1.676	2.009	2.311	2.678	2.937	3.496
60	1.296	1.458	1.671	2.000	2.299	2.660	2.915	3.460
70	1.294	1.456	1.667	1.994	2.291	2.648	2.899	3.435
80	1.292	1.453	1.664	1.990	2.284	2.639	2.887	3.416
100	1.290	1.451	1.660	1.984	2.276	2.626	2.871	3.390
1000	1.282	1.441	1.646	1.962	2.245	2.581	2.813	3.300
Infinite	1.282	1.440	1.645	1.960	2.241	2.576	2.807	3.291

Now for Vendor set1 and Vendor set2, with and without Industry 4.0 implementation, the calculation is as follows-

Table 4.16 Sample mean table for Supplier set 1 and 2

		Ā1	1.48		Ā2	0.51
PARTS	**A1**	**A1-Ā1**		**A2**	**A2-Ā2**	
Carrier Housing	1.98	0.51	0.26	0.57	0.06	0.00
Rear Hub	0.54	-0.94	0.88	0.23	-0.28	0.08
Case cover	0.33	-1.15	1.31	0.10	-0.41	0.17
SBA Mtg Bracket	0.21	-1.27	1.60	0.08	-0.43	0.18
Crown Wheel	1.17	-0.31	0.10	0.24	-0.27	0.07
Pinion	0.51	-0.96	0.93	0.10	-0.40	0.16
Saddle	0.10	-1.38	1.91	0.02	-0.48	0.23
RA Beam	7.77	6.29	39.55	2.93	2.43	5.89
RA Brake pressure plate	0.68	-0.79	0.63	0.28	-0.22	0.05
	13.29		47.16	4.55		6.83
		Ā3	1.11		Ā4	0.37
PARTS	**A3**	**A3-Ā3**		**A4**	**A4-Ā4**	
Carrier Housing	4.13	0.62	0.39	0.64	0.27	0.07
Rear Hub	2.22	1.11	1.24	0.83	0.47	0.22
Case cover	0.46	-0.66	0.43	0.16	-0.20	0.04
SBA Mtg Bracket	0.53	-0.58	0.34	0.20	-0.17	0.03
Crown Wheel	0.93	-0.18	0.03	0.16	-0.20	0.04
Pinion	0.35	-0.76	0.58	0.06	-0.30	0.09
Saddle	0.24	-0.87	0.76	0.06	-0.31	0.09
RA Beam	2.97	1.86	3.46	0.95	0.59	0.35
RA Brake pressure plate	0.57	-0.54	0.30	0.22	-0.14	0.02
	10.00		7.52	3.30		0.95

Ā1=1.48, Ā2=0.51, Ā3=1.11, Ā4=0.37

n1=9, n2=9, n3=9, n4=9, s1=2.43, s2=0.92, s3=0.97, s=0.34

S_{set1}=0.87, S_{set2}=0.53, $t_{set1}=\frac{1.48-0.51}{0.87\sqrt{(\frac{1}{9}+\frac{1}{9})}}$ = 2.36, $t_{set2}=\frac{1.11-0.37}{0.53\sqrt{(\frac{1}{9}+\frac{1}{9})}}$ = 2.96

$S_{set1}=\frac{(n1-1)s1^2+(n2-1)s2^2}{n1+n2-2}$ = 0.87, $S_{set2}=\frac{(n1-1)s1^2+(n2-1)s2^2}{n1+n2-2}$ = 0.53

df_{set1}= n1+n2-2 = 9+9-2 = 16, t value from table is 2.120 for df_{16}

The calculated t value is higher than the critical T-value from the table, hence it is concluded that the difference between the means for the two groups is significantly different. The table of change of the inventory value with its change percentage is displayed below.

Table 4.17 Total Inventory performance after Industry 4.0 implementation

PARTS	**CLASSIFICATION**	**SUPPLIER1**	**PAST TOTAL INVENTORY**	**TOTAL INVENTORY AFTER INDUSTRY 4.0**	
Carrier Housing	Casting	MAVAL FOUNDARY	19848000	5688000	71 %
Rear Hub	Casting	MAVAL FOUNDARY	5377736	2276976	58 %
Case cover	Casting	MAVAL FOUNDARY	3313725	967725	71 %
SBA Mtg Bracket	Casting	MAVAL FOUNDARY	2115100	776100	63 %
Crown Wheel	Forging	ECHJAY FORGINGS	11653400	2369400	80 %
Pinion	Forging	ECHJAY FORGINGS	5138090	1044690	80 %
Saddle	Forging	ECHJAY FORGINGS	956000	246000	74 %
RA Beam	Sheet metal	RSB INDUSTRIES	77652000	29322000	62 %
RA Brake pressure plate	Sheet metal	BRAKES INDIA	6847600	2835600	59 %
PARTS	**CLASSIFICATION**	**SUPPLIER2**	**PAST TOTAL INVENTORY**	**TOTAL INVENTORY AFTER INDUSTRY 4.0**	
Carrier Housing	Casting	MUTHA ENGG	17339600	6351600	63 %
Rear Hub	Casting	MUTHA ENGG	22221108	8314488	63 %
Case cover	Casting	MUTHA ENGG	4550000	1638000	64 %
SBA Mtg Bracket	Casting	MUTHA ENGG	5315780	2005980	62 %
Crown Wheel	Forging	ANC	9286750	1641750	82 %
Pinion	Forging	ANC	3495195	617895	82 %
Saddle	Forging	ANC	2396000	606000	75 %
RA Beam	Sheet metal	AXLE INDIA	29706400	9542400	68 %
RA Brake pressure plate	Sheet metal	MERITOR	5659720	2232120	61 %

With above table, it is concluded that there is 69% of improvement in inventory on an average for all three commodities of Casting, Forging and Sheet metal after implementation of Industry4.0 in Production planning and control.

4.9 Concluding Remarks

In this chapter, the various contributions of this research have been outlined, focusing on theoretical, research, and managerial dimensions. The study offers a comprehensive framework for understanding and implementing Industry 4.0 in production planning and control, specifically within the Indian automobile industry. The theoretical contribution enriches existing knowledge by providing a multidimensional framework for assessing readiness, identifying enablers and barriers, and analyzing their contextual relationships.

From a research perspective, the methodological innovation of integrating Fuzzy Delphi, Fuzzy COPRAS, Fuzzy Best-Worst Method (BWM), and Fuzzy ISM strengthens the reliability and applicability of the findings. By applying these techniques in a real-world pilot project from one of India’s leading automobile companies, the study bridges the gap between academic research and practical industry challenges, offering a robust foundation for future research.

Managerially, the study provides a strategic roadmap for Industry 4.0 implementation, offering practical guidelines for automobile companies and their supply chains to achieve a "Connected Organization." The step-by-step approach enables industries to begin their Industry 4.0 journey while ensuring alignment across all tiers of production and supply chain operations.

In summary, this chapter highlights the significant theoretical, research, and practical contributions of the study, all of which are aimed at facilitating the successful adoption of Industry 4.0 in production planning and control. The insights and recommendations provided will not only benefit the Indian automobile industry but also serve as a guide for other industries aiming to embrace digital transformation in their production and supply chain operations.

Chapter 5

SUMMARY & CONCLUSION

Chapter Overview

This chapter summarizes the overall research work with their results and shows the uniqueness of the research work. This section also shows the suggestions and recommendations for future research work with limitations for current research work on the subject followed by the implications.

5.1 Introduction

Industry 4.0 has become a driving force in the transformation of industries, particularly in enhancing operational efficiency and maintenance processes. However, despite its growing adoption, industries continue to face significant challenges in synchronizing their supply chain and production planning systems, especially when collaborating with dependent stakeholders and interrelated industries. While each company strives for improvement through Industry 4.0 technologies, the broader issues of demand-supply integration and production planning—often governed by buyer or supplier plants—remain unresolved.

This chapter presents a comprehensive summary of the research undertaken, emphasizing the study's strengths and uniqueness, followed by practical recommendations, limitations, and suggestions for future research. The research aimed to bridge the gap between industries by addressing the challenges of inventory management, cash flow optimization, and stakeholder alignment in the Indian automobile industry, specifically within the context of production planning and control (PPC).

5.2 Summary of the Study Undertaken

The study focused on assessing the readiness of the Indian automobile industry for Industry 4.0 implementation, with a particular emphasis on PPC. A structured methodological framework was employed, combining qualitative and quantitative techniques, such as Systematic Literature Review (SLR), Fuzzy Delphi, Fuzzy COPRAS, Fuzzy Best-Worst Method (BWM), and Fuzzy ISM, to identify and analyze key factors influencing Industry 4.0 adoption.

By engaging with senior professionals from automobile manufacturers' PPC departments, the study identified both catalysts and impediments to Industry 4.0 implementation. Experts rated various readiness factors and participated in multiple Delphi rounds, leading to a refined list of enablers and barriers that can guide companies in their digital transformation. The study also explored the critical role of inter-industry synchronization in improving demand-supply balance and streamlining inventory management and cash flows.

5.3 Strength and Uniqueness of the Study

This study offers several strengths and unique contributions to the field of Industry 4.0 research:

1. **Holistic Approach**: Unlike most studies that focus on internal process optimization within a single company, this research emphasizes the importance of inter-industry collaboration. It addresses the synchronization of supply chain processes across Tier 1, 2, and 3 suppliers, highlighting the need for real-time communication and alignment between manufacturers and their stakeholders.

2. **Methodological Rigor**: The study combines advanced techniques like Fuzzy Delphi, Fuzzy COPRAS, Fuzzy BWM, and Fuzzy ISM, ensuring a robust analysis of qualitative and quantitative data. These methods enabled the research to prioritize and rank key readiness factors, enablers, and impediments in a structured and reliable manner, making the findings more practical for real-world application.

3. **Pilot Project-Based Insights**: The study's foundation lies in a pilot project conducted within one of India's leading automobile manufacturers. This real-world application adds depth and relevance to the findings, providing actionable insights for other companies in the industry.

4. **Practical Contributions**: The study delivers a step-by-step guideline for implementing Industry 4.0 in PPC, making it a practical resource for industries not only within the automobile sector but across other domains. It provides a comprehensive framework for starting Industry 4.0 journeys in PPC and supply chain management (SCM) systems.

5.4 Suggestions and Recommendations

Based on the research findings, the following key recommendations are made for the effective implementation of Industry 4.0 in PPC:

1. **Focus on Inter-Industry Synchronization**: Industries must move beyond internal improvements and work on synchronizing their operations with suppliers and other stakeholders. Establishing real-time data sharing and connectivity across the supply chain can help mitigate inefficiencies and enhance demand-supply balance, ultimately enabling a "Connected Organization" approach.

2. **Investment in Technology and Skills**: While the initial cost of implementing Industry 4.0 can be high, the long-term benefits—such as enhanced efficiency, better inventory management, and streamlined operations—far outweigh the investment. Companies should prioritize both technological upgrades and employee training to make the most of Industry 4.0 tools.

3. **Lean Production Integration**: The integration of lean production principles with Industry 4.0 technologies should be a priority. By minimizing waste, reducing overproduction, and optimizing production cycles, industries can maximize the efficiency of their supply chains.

4. **Development of Effective Dashboards**: A comprehensive dashboard that offers real-time visibility into production and supply chain operations should be developed. This tool can help industries monitor key metrics from raw material procurement to after-sales services, ensuring that production schedules align with market demand and supply chain dynamics.

5.5 Implications

The implications of this study can be categorized into four key areas: academic, managerial, methodological, and societal.

5.5.1 Academic Implications

This research contributes significantly to the academic literature on Industry 4.0 by addressing the gap between theoretical frameworks and practical applications in production planning and control. It highlights the need for interdisciplinary approaches that encompass supply chain management, operational excellence, and digital transformation. The findings can be used as a basis for future studies that explore similar issues in different sectors or geographical contexts, enhancing the body of knowledge surrounding Industry 4.0.

5.5.2 Managerial Implications

The findings of this study offer actionable insights for managers across various manufacturing sectors, including the **automotive industry, auto parts manufacturing, fast-moving consumer goods (FMCG), and other industrial domains**. By identifying the key **catalysts** and **impediments** to Industry 4.0 implementation, industry leaders can develop targeted strategies to enhance technological adoption, optimize production planning, and improve supply chain efficiency.

Implications for the Automotive Industry

For **automobile manufacturers**, adopting Industry 4.0 technologies such as **cyber-physical systems, real-time data analytics, and AI-driven decision-making** can significantly enhance **production efficiency, predictive maintenance, and inventory management**. However, challenges such as **legacy infrastructure, high capital investments, and workforce skill gaps** must be addressed through structured **change management programs, reskilling initiatives, and phased technology integration**.

Additionally, synchronizing Industry 4.0 adoption across the **OEMs (original equipment manufacturers) and tiered suppliers** will enhance end-to-end visibility in the **supply chain**, reducing disruptions and improving Just-in-Time (JIT) manufacturing efficiency.

Implications for the Auto Parts Sector

The **auto parts industry**, which serves as a backbone to automotive manufacturers, faces unique challenges such as **demand variability, production scalability, and cost pressures**. Industry 4.0 adoption in this sector can enable:

- **Smart manufacturing** to enhance flexibility and reduce defects in components.
- **IoT-enabled tracking systems** to optimize logistics and supplier integration.
- **Digital twins** for simulating production processes before implementation, improving efficiency.

For small and medium enterprises (SMEs) in this sector, government incentives and industry collaboration can facilitate smoother transitions to digitalized operations.

Implications for the FMCG Sector

The **FMCG industry**, characterized by high-volume, low-margin production, can leverage Industry 4.0 to enhance **automation, predictive analytics, and demand forecasting**. Specific managerial actions include:

- **AI-driven supply chain planning** to reduce inventory shortages and excess stock.
- **Automated quality control** to enhance product consistency and compliance with stringent regulations.
- **Integration of smart packaging** with IoT for real-time tracking and traceability.

A major challenge in this sector is **ensuring digital synchronization between manufacturers, distributors, and retailers**. Standardized data-sharing mechanisms and cross-industry collaboration can help mitigate this issue.

Implications for All Manufacturing Sectors

Across all manufacturing domains, the study highlights the need for:

1. **Inter-industry Synchronization** – Collaboration between industries to develop common Industry 4.0 frameworks, ensuring interoperability in supply chains.
2. **Investment in Scalable Technologies** – Adoption of **modular automation, AI-driven analytics, and digital twin technology** to improve adaptability and reduce downtime.
3. **Lean Integration** – Combining Industry 4.0 with **lean manufacturing principles** to minimize waste, optimize resource utilization, and improve agility.
4. **Workforce Upskilling** – Training employees in **digital skills, AI-driven decision-making, and cybersecurity protocols** to maximize the benefits of Industry 4.0.

By implementing these recommendations, managers can make informed decisions, enhance **operational efficiency, resilience, and competitiveness**, and pave the way for a **sustainable, technology-driven future** in manufacturing.

study provides actionable insights for managers in the automobile industry and beyond. By identifying the key catalysts and impediments to Industry 4.0 implementation, managers can develop targeted strategies that address these challenges. Furthermore, the recommendations for inter-industry synchronization, investment in technology, and lean integration can guide decision-making processes, ultimately leading to more efficient production planning and supply chain management.

5.5.3 Methodological Implications

This study employs a **rigorous mixed-methods approach**, combining both **qualitative and quantitative methodologies**, to examine the complex and dynamic transformation associated with **Industry 4.0 implementation in production planning and control**. The integration of advanced **fuzzy-based multi-criteria decision-making (MCDM) techniques** demonstrates the strength of methodological triangulation in addressing uncertainties and subjectivity inherent in industrial decision-making. The methodological implications of this research extend beyond the automobile industry, offering valuable insights for scholars and practitioners studying technological adoption in manufacturing and other complex domains.

Robustness of Mixed-Methods Approach

By integrating **qualitative (Systematic Literature Review, Extensive Literature Review, Delphi study)** and **quantitative (Fuzzy COPRAS, Fuzzy BWM, Fuzzy ISM)** methods, this study showcases a **holistic** approach to understanding Industry 4.0 adoption. This methodological framework enables:

- **Deeper exploration of industry challenges and enablers** through expert-driven qualitative insights.
- **Objective prioritization of key factors** affecting implementation using advanced quantitative techniques.
- **Contextual analysis of interrelationships** among catalysts and impediments, which would be difficult to capture through conventional methods.

This multi-pronged approach can serve as a **benchmark for future research in industrial digital transformation**.

Contribution of Fuzzy-Based MCDM Techniques

The study employs four key **fuzzy-based methodologies**, each contributing uniquely to analyzing **Industry 4.0 readiness and implementation challenges**:

1. **Fuzzy Delphi Method** – Helps in filtering and refining expert opinions to identify the most relevant catalysts and impediments, reducing bias and improving consensus-building in qualitative research.

2. **Fuzzy COPRAS (Complex Proportional Assessment)** – Enables ranking and evaluation of **Industry 4.0 readiness factors**, making it possible to assess the degree of preparedness across different sectors objectively.

3. **Fuzzy BWM (Best-Worst Method)** – Effectively prioritizes the most critical catalysts and impediments by addressing inconsistencies in decision-making, offering a **more reliable ranking mechanism** than traditional weight assignment methods.

4. **Fuzzy ISM (Interpretive Structural Modeling)** – Establishes **causal relationships** among identified factors, facilitating a **hierarchical understanding** of how different elements interact within the industry 4.0 framework.

These methods provide a more **nuanced, structured, and quantitative** perspective on expert-driven qualitative insights, reducing uncertainty and enhancing the robustness of decision-making frameworks in industrial studies.

Applicability Across Different Research Domains

The methodological framework adopted in this study is not only applicable to **Industry 4.0 research in the automobile sector** but can also be extended to **other manufacturing industries, supply chain management, and digital transformation studies**. Potential research applications include:

- **Assessing digital transformation readiness** in industries such as **FMCG, auto parts, aerospace, pharmaceuticals, and electronics manufacturing**.

- **Evaluating the impact of emerging technologies** (e.g., AI, IoT, Blockchain) on supply chain resilience using similar fuzzy-based techniques.

- **Developing structured decision-making frameworks** for complex industrial problems that involve multiple, interrelated variables with uncertainty.

Encouraging Future Research in Mixed-Methods Approaches

This study underscores the **importance of methodological pluralism** in industrial research. Future researchers can build upon this work by:

- Exploring **hybrid methodologies**, combining fuzzy logic with machine learning, simulation modeling, or optimization techniques.
- Extending **comparative analyses** using alternative MCDM approaches, such as **Fuzzy DEMATEL, AHP, or TOPSIS**, to validate findings.
- Conducting **longitudinal studies** to track Industry 4.0 adoption over time using a similar fuzzy-based analytical framework.

By demonstrating the effectiveness of **fuzzy-based mixed methods**, this research paves the way for **more comprehensive, data-driven decision-making models** in industrial transformation studies.

5.5.4 Societal Implications

This research highlights the transformative role of **Industry 4.0** in fostering **sustainable industrial practices**, particularly in the **automobile sector and other manufacturing industries**. By improving **operational efficiency, supply chain optimization, and data-driven decision-making**, Industry 4.0 technologies contribute to **economic growth, job creation, environmental sustainability, and resource efficiency**. Beyond economic and industrial benefits, the combination of **Industry 4.0 and lean manufacturing** principles enhances sustainability by reducing **carbon emissions, lowering pollution, and minimizing waste**, ultimately benefiting society as a whole.

Industry 4.0 technologies enable more **sustainable and environmentally friendly manufacturing practices** by minimizing waste, reducing energy consumption, and optimizing logistics. **IoT-enabled monitoring systems** allow industries to track and optimize energy usage in real time, significantly reducing **electricity consumption** and associated **CO_2 emissions**. **AI-driven predictive maintenance** prevents unnecessary breakdowns and overuse of machinery, extending equipment life and **reducing the carbon footprint** of industrial operations. **Automation and robotics** further minimize human intervention, reducing excess material usage and leading to **less industrial waste generation**.

The integration of **lean manufacturing with Industry 4.0** further enhances sustainability by **eliminating non-value-adding activities, reducing defects, and improving process efficiency**. Lean principles such as **Just-in-Time (JIT) manufacturing, continuous improvement (Kaizen), and value stream mapping** ensure that production aligns precisely with demand, minimizing overproduction and excessive resource consumption. Lean manufacturing also promotes the use of **lightweight materials, optimized layouts, and reduced transportation waste**, all of which contributes to lower carbon emissions and a smaller environmental footprint.

In supply chain and transportation, **AI and big data analytics** help optimize logistics routes, reducing **fuel consumption and greenhouse gas emissions**. **Blockchain-based smart contracts** enhance transparency and reduce inefficiencies in supply chains, leading to **less overproduction and wasteful inventory management**. By synchronizing lean supply chains with **digital twin simulations and real-time analytics**, industries can predict demand fluctuations more accurately and prevent unnecessary transportation-related emissions.

Industry 4.0 and lean manufacturing also support **circular economy principles**, encouraging manufacturers to design products for **reusability, remanufacturing, and recycling**, which significantly reduces waste and pollution. **3D printing (additive manufacturing)** enables precise material usage, minimizing industrial scrap and landfill waste. **AI-driven material sorting and waste recycling** improve waste management efficiency, ensuring fewer pollutants enter the environment. **Smart factories using digital twins** simulate different production scenarios, identifying low-waste and eco-friendly alternatives.

With the integration of **IoT sensors and AI-based monitoring**, industries can track and regulate air quality in real time, adjusting processes to limit emissions. **Electrification of manufacturing processes** reduces reliance on fossil fuels, cutting down **industrial smoke, NOx, and SOx emissions**. **Automated HVAC and lighting systems** in smart factories dynamically adjust based on real-time occupancy and needs, reducing **excess energy usage** and lowering indirect emissions. The adoption of **lean energy management systems** ensures that no unnecessary power is wasted, further decreasing the carbon footprint of industrial operations.

While Industry 4.0 adoption leads to **automation-driven changes in employment**, it also creates **new job opportunities in green technologies, AI-driven sustainability, and digitalized manufacturing processes**. **Upskilling programs** in digital and lean methodologies allow workers to transition into **sustainable manufacturing roles**, fostering long-term economic and environmental benefits. The rise of **green engineering jobs** focusing on **eco-friendly production techniques** contributes to broader sustainability efforts. Collaborative efforts between **academia, industry, and policymakers** can further enhance innovation in sustainable manufacturing.

The impact of Industry 4.0 extends beyond manufacturing, benefiting consumers and society as a whole. Smart technologies enhance **product quality, durability, and customization**, reducing the need for frequent replacements and lowering consumer-driven waste. **Sustainable mobility solutions**, such as **electric vehicle (EV) adoption and smart transportation networks**, lead to a reduction in urban air pollution. **Transparency in production** through blockchain and digital tracking enables consumers to make **environmentally conscious purchasing decisions**.

By integrating **smart manufacturing, lean principles, automation, and digital sustainability strategies**, Industry 4.0 plays a pivotal role in **reducing carbon emissions, lowering industrial pollution, and fostering environmental responsibility**. These technological advancements not only benefit manufacturers but also contribute to a **cleaner, healthier society with improved air quality, resource efficiency, and economic resilience**.

5.6 Limitations

While the study provides valuable insights, several limitations must be acknowledged:

1. **Geographical and Sector-Specific Focus**: The study focuses on the Indian automobile industry, which may limit the applicability of its findings to other industries or regions. Although the principles of Industry 4.0 are broadly applicable, the specific challenges faced by the Indian market may not be fully representative of those in other contexts.

2. **Dependence on Expert Opinions**: The study relies heavily on the subjective judgments of experts through the Fuzzy Delphi method. While efforts were made to minimize bias through multiple rounds of validation, the final list of factors may still reflect individual viewpoints.

3. **Lack of Cost-Benefit Analysis**: Although cost emerged as a concern among participants, the study does not delve deeply into a financial cost-benefit analysis of Industry 4.0 adoption. Future research should explore this aspect to offer industries a clearer understanding of the potential return on investment.

5.7 Future Research Directions

Several avenues for future research emerge from this study:

1. **Implementation Strategy Development**: Future studies should focus on creating comprehensive implementation strategies that address cost concerns, resource allocation, and organizational readiness. A phased approach to Industry 4.0 adoption could help industries better manage their digital transformation efforts.

2. **Lean-Industry 4.0 Integration**: Further research is needed to explore how lean production principles can be integrated with Industry 4.0 technologies to reduce waste and inefficiencies. A combined lean-digital approach can optimize production planning, enhance supply chain performance, and decrease excess inventory and production losses.

3. **Real-Time Dashboard Development**: Future work should focus on creating real-time dashboards that allow companies to monitor their entire supply chain, from raw material procurement to customer delivery. Such tools would enable better decision-making and improved alignment of production schedules with demand.

4. **Broader Industry Application**: While this study focuses on the automobile industry, future research should extend these findings to other industries, such as consumer goods, pharmaceuticals, or electronics, to examine whether similar readiness factors, catalysts, and impediments exist.

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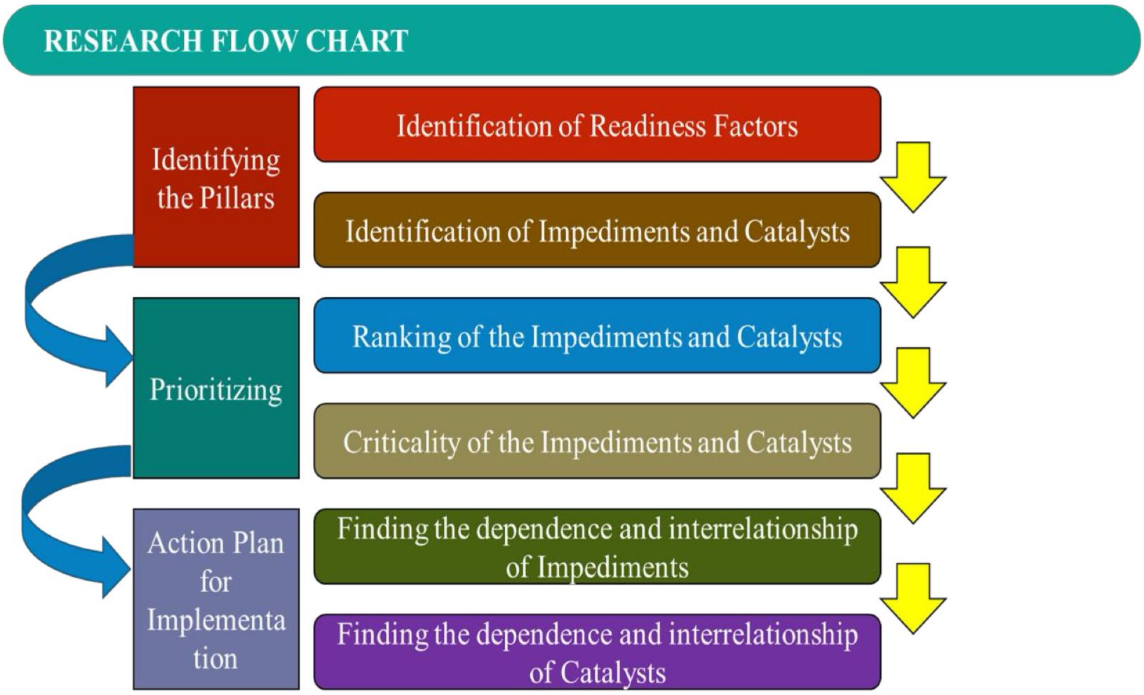
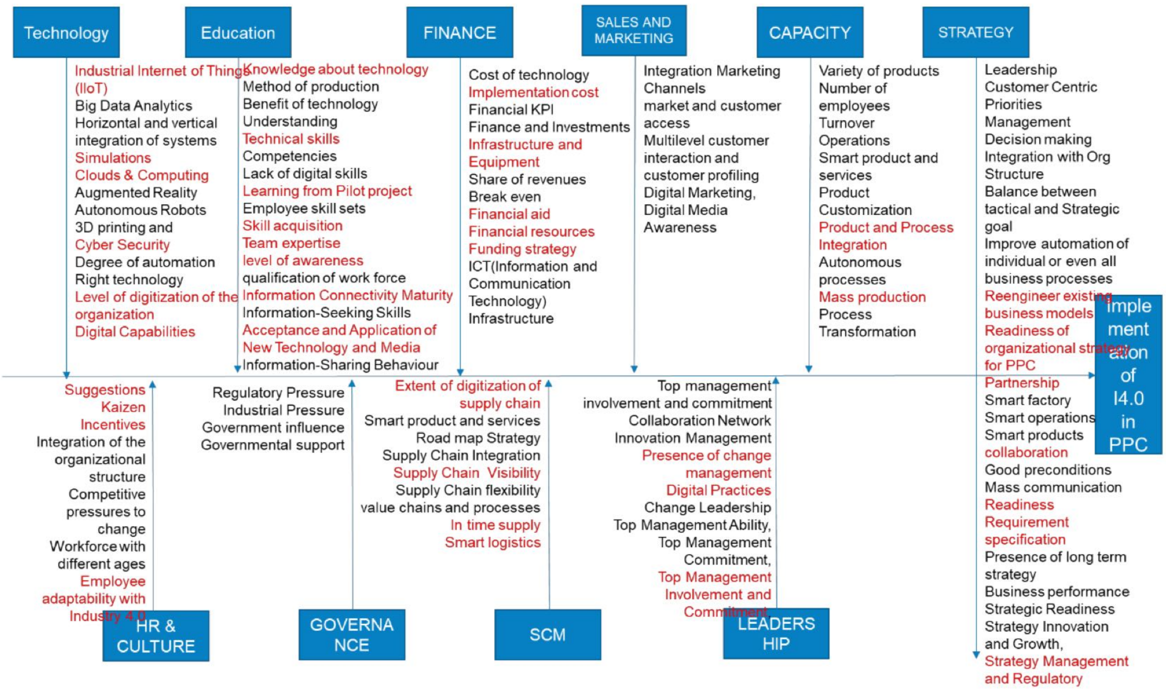
Appendices

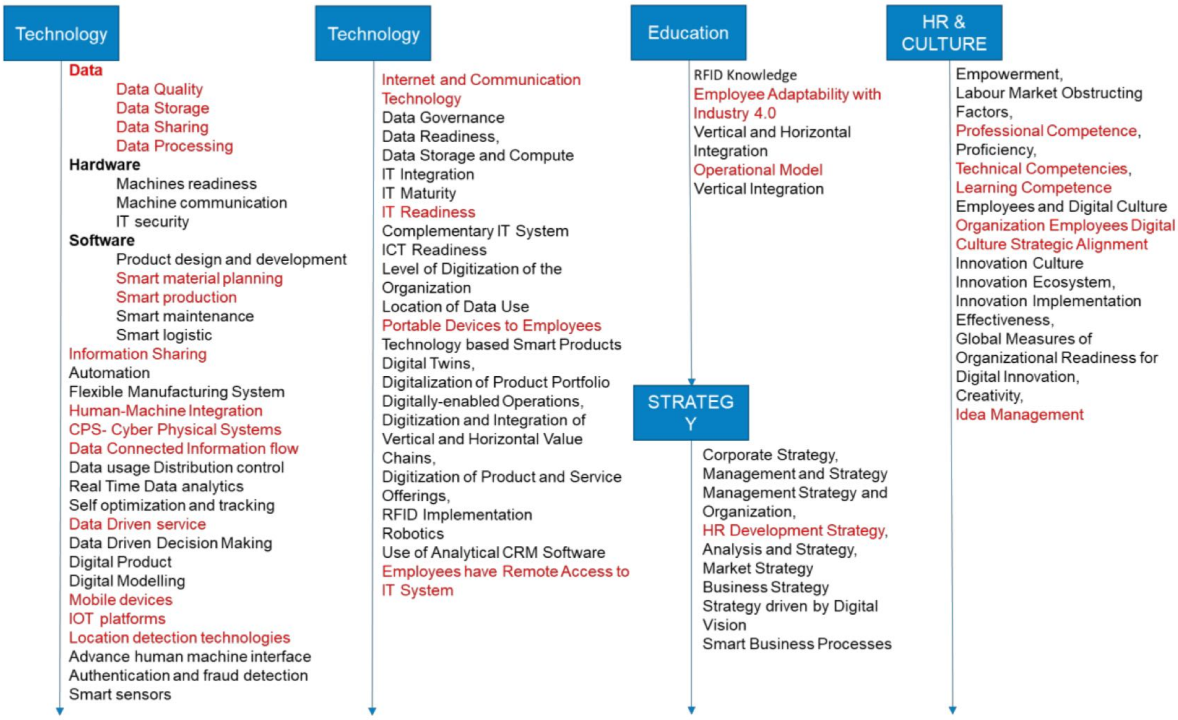
Appendix A. Research flow chart

To start the research work on the topic, data was collected from intense literature review and then analyzed with the help of Delphi study to find out the most important readiness factors among identified 182 readiness factors.

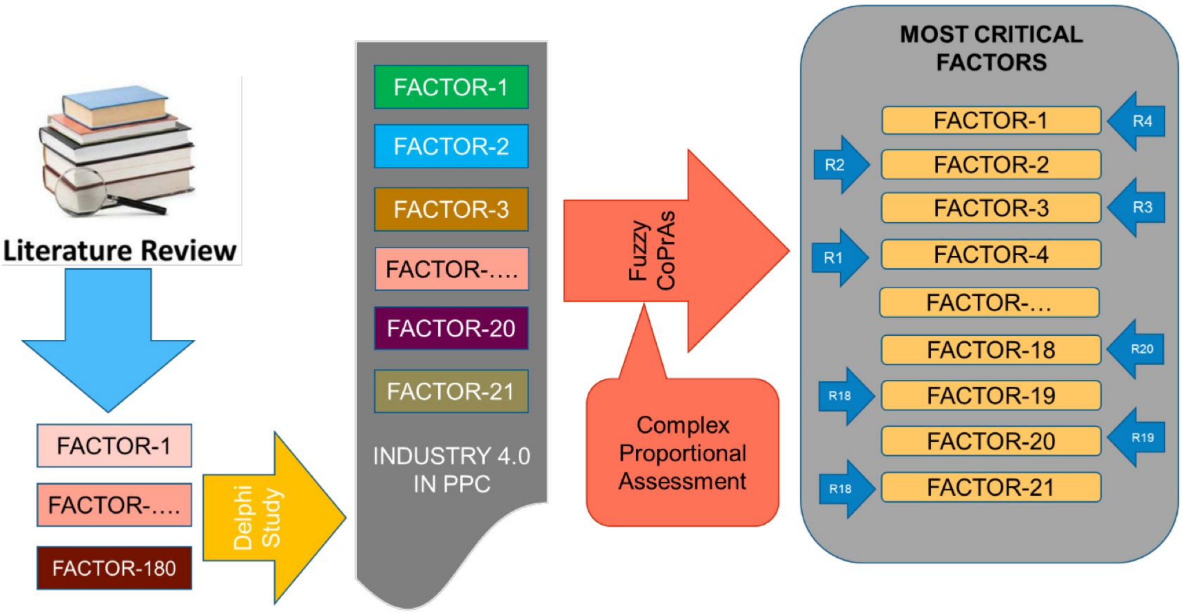


Below are the list of readiness factors identified from in depth literature review

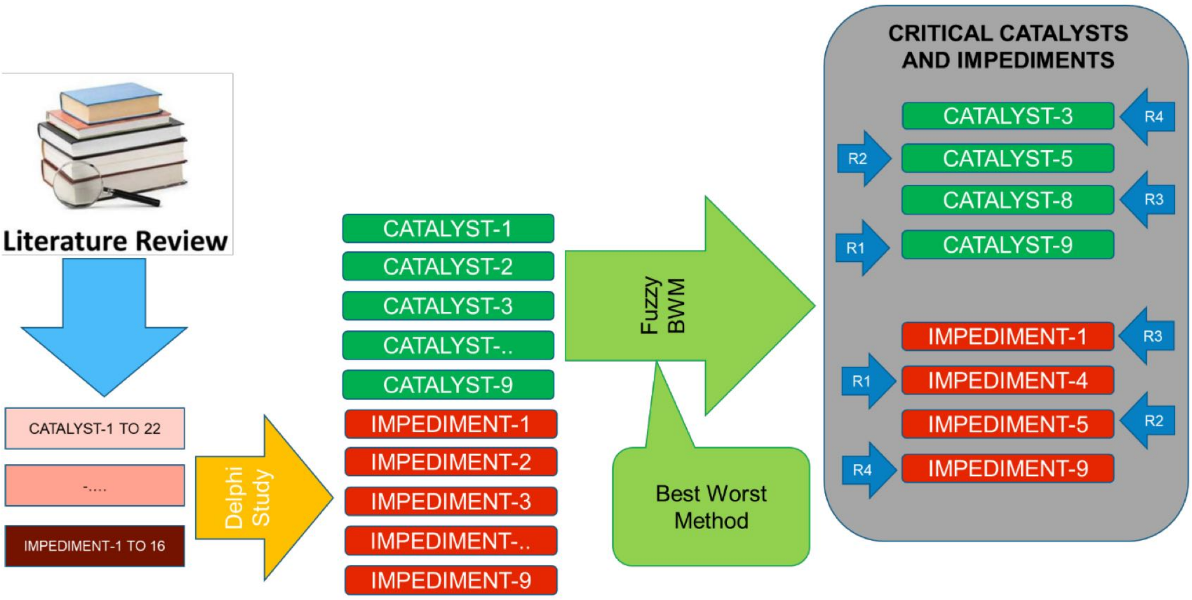

Technology
Industrial Internet of Things (IIoT)
Big Data Analytics
Horizontal and vertical integration of systems
Simulations
Clouds & Computing
Augmented Reality
Autonomous Robots
3D printing and
Cyber Security
Degree of automation
Right technology
Level of digitization of the organization
Digital Capabilities
Education
Knowledge about technology
Method of production
Benefit of technology
Understanding
Technical skills
Competencies
Lack of digital skills
Learning from Pilot project
Employee skill sets
Skill acquisition
Team expertise
level of awareness
qualification of work force
Information Connectivity Maturity
Information-Seeking Skills
Acceptance and Application of New Technology and Media
Information-Sharing Behaviour
FINANCE
Cost of technology
Implementation cost
Financial KPI
Finance and Investments
Infrastructure and Equipment
Share of revenues
Break even
Financial aid
Financial resources
Funding strategy
ICT(Information and Communication Technology) Infrastructure
SALES AND MARKETING
Integration Marketing Channels
market and customer access
Multilevel customer interaction and customer profiling
Digital Marketing,
Digital Media Awareness
CAPACITY
Variety of products
Number of employees
Turnover
Operations
Smart product and services
Product Customization
Product and Process Integration
Autonomous processes
Mass production
Process Transformation
STRATEGY
Leadership
Customer Centric
Priorities
Management
Decision making
Integration with Org Structure
Balance between tactical and Strategic goal
Improve automation of individual or even all business processes
Reengineer existing business models
Readiness of organizational strategy for PPC
Partnership
Smart factory
Smart operations
Smart products
collaboration
Good preconditions
Mass communication
Readiness
Requirement specification
Presence of long term strategy
Business performance
Strategic Readiness
Strategy Innovation and Growth,
Strategy Management and Regulatory
Implementation of I4.0 in PPC
Suggestions
Kaizen
Incentives
Integration of the organizational structure
Competitive pressures to change
Workforce with different ages
Employee adaptability with Industry 4.0
HR & CULTURE
Regulatory Pressure
Industrial Pressure
Government influence
Governmental support
GOVERNANCE
Extent of digitization of supply chain
Smart product and services
Road map Strategy
Supply Chain Integration
Supply Chain Visibility
Supply Chain flexibility
value chains and processes
In time supply
Smart logistics
SCM
Top management involvement and commitment
Collaboration Network
Innovation Management
Presence of change management
Digital Practices
Change Leadership
Top Management Ability,
Top Management Commitment,
Top Management Involvement and Commitment
LEADERSHIP


Technology
Data
Data Quality
Data Storage
Data Sharing
Data Processing
Hardware
Machines readiness
Machine communication
IT security
Software
Product design and development
Smart material planning
Smart production
Smart maintenance
Smart logistic
Information Sharing
Automation
Flexible Manufacturing System
Human-Machine Integration
CPS- Cyber Physical Systems
Data Connected Information flow
Data usage Distribution control
Real Time Data analytics
Self optimization and tracking
Data Driven service
Data Driven Decision Making
Digital Product
Digital Modelling
Mobile devices
IOT platforms
Location detection technologies
Advance human machine interface
Authentication and fraud detection
Smart sensors
Technology
Internet and Communication Technology
Data Governance
Data Readiness,
Data Storage and Compute
IT Integration
IT Maturity
IT Readiness
Complementary IT System
ICT Readiness
Level of Digitization of the Organization
Location of Data Use
Portable Devices to Employees
Technology based Smart Products
Digital Twins,
Digitalization of Product Portfolio
Digitally-enabled Operations,
Digitization and Integration of Vertical and Horizontal Value Chains,
Digitization of Product and Service Offerings,
RFID Implementation
Robotics
Use of Analytical CRM Software
Employees have Remote Access to IT System
Education
RFID Knowledge
Employee Adaptability with Industry 4.0
Vertical and Horizontal Integration
Operational Model
Vertical Integration
STRATEGY
Corporate Strategy,
Management and Strategy
Management Strategy and Organization,
HR Development Strategy,
Analysis and Strategy,
Market Strategy
Business Strategy
Strategy driven by Digital Vision
Smart Business Processes
HR & CULTURE
Empowerment,
Labour Market Obstructing Factors,
Professional Competence,
Proficiency,
Technical Competencies,
Learning Competence
Employees and Digital Culture
Organization Employees Digital Culture Strategic Alignment
Innovation Culture
Innovation Ecosystem,
Innovation Implementation Effectiveness,
Global Measures of Organizational Readiness for Digital Innovation,
Creativity,
Idea Management

For finding out the most critical catalysts, below process flow chart is followed



For finding out the most critical impediments, below process flow chart is followed



Appendix B. Survey Questions

Readiness Factors for Delphi study

Sr. No	Parent group	Readiness Factors	1	2	3	4	5
1	Technology	Requirement of Industrial Internet of Things (IIoT) in Industry for implementation of INDUSTRY 4.0 in PPC					
2	Technology	Requirement of Big Data Analytics in Industry for implementation of INDUSTRY 4.0 in PPC					
3	Technology	Industries should be doing Horizontal and vertical integration of systems for implementation of INDUSTRY 4.0 in PPC					
4	Technology	Industries having Simulation facility of production for implementation of INDUSTRY 4.0 in PPC					
5	Technology	Requirement of Clouds & Computing for implementation of INDUSTRY 4.0 in PPC					
6	Technology	Requirement of Augmented Reality in Industry for implementation of INDUSTRY 4.0 in PPC					
7	Technology	Requirement of Autonomous Robots in industry for implementation of INDUSTRY 4.0 in PPC					
8	Technology	Requirement of 3D printing and Cyber Security in industry for implementation of INDUSTRY 4.0 in PPC					
9	Technology	Requirement of any Degree of automation in industry for implementation of INDUSTRY 4.0 in PPC					
10	Technology	Usage of Right technology for Industry 4.0 in Industry for implementation of INDUSTRY 4.0 in PPC					
11	Technology	Level of digitization of the organization for implementation of INDUSTRY 4.0 in PPC					

12	Technology	Digital Capabilities of the industry for implementation of INDUSTRY 4.0 in PPC					
13	Technology	Level of Data Quality of the industry for implementation of INDUSTRY 4.0 in PPC					
14	Technology	Capacity of Data Storage of the industry for implementation of INDUSTRY 4.0 in PPC					
15	Technology	Technology required for Data Sharing for implementation of INDUSTRY 4.0 in PPC					
16	Technology	Technology required for Data Processing for implementation of INDUSTRY 4.0 in PPC					
17	Technology	Machines readiness- Hardware component for implementation of INDUSTRY 4.0 in PPC					
18	Technology	Machine communication- Hardware component for implementation of INDUSTRY 4.0 in PPC					
19	Technology	IT security- Software component for implementation of INDUSTRY 4.0 in PPC					
Sr. No	**Parent group**	**Readiness Factors**					
20	Technology	Product design and development – Software Component for implementation of INDUSTRY 4.0 in PPC					
21	Technology	Smart material planning – Software Component for implementation of INDUSTRY 4.0 in PPC					
22	Technology	Smart production – Software Component for implementation of INDUSTRY 4.0 in PPC					
23	Technology	Smart maintenance- Software Component for implementation of INDUSTRY 4.0 in PPC					
24	Technology	Smart logistic- Software component for implementation of INDUSTRY 4.0 in PPC					
25	Technology	Technology required for Information Sharing for implementation of INDUSTRY 4.0 in PPC					
26	Technology	Level of Automation in industry for implementation of INDUSTRY 4.0 in PPC					

27	Technology	Presence of Flexible Manufacturing System for implementation of INDUSTRY 4.0 in PPC					
28	Technology	Requirement of Human-Machine Integration for implementation of INDUSTRY 4.0 in PPC					
29	Technology	Requirement of CPS- Cyber Physical Systems for implementation of INDUSTRY 4.0 in PPC					
30	Technology	Requirement of Data Connected Information f2 for implementation of INDUSTRY 4.0 in PPC					
31	Technology	Requirement of Data usage Distribution control for implementation of INDUSTRY 4.0 in PPC					
32	Technology	Availability of Real Time Data analytics in industry for implementation of INDUSTRY 4.0 in PPC					
33	Technology	Availability of Self optimization and tracking system in industry for implementation of INDUSTRY 4.0 in PPC					
34	Technology	Requirement of Data Driven services in industry for implementation of INDUSTRY 4.0 in PPC					
35	Technology	Requirement of Data Driven Decision Making in industry for implementation of INDUSTRY 4.0 in PPC					
36	Technology	Requirement of Digital Products in industry for implementation of INDUSTRY 4.0 in PPC					
37	Technology	Requirement of Digital Modelling in industry for implementation of INDUSTRY 4.0 in PPC					
38	Technology	Requirement of Mobile devices in industry for implementation of INDUSTRY 4.0 in PPC					
39	Technology	Requirement of IOT platforms for implementation of INDUSTRY 4.0 in PPC					
40	Technology	Requirement of Location detection technologies for implementation of INDUSTRY 4.0 in PPC					
41	Technology	Requirement of Advance human machine interface in industry for implementation of INDUSTRY 4.0 in PPC					

42	Technology	Availability of Authentication and fraud detection system in industry for implementation of INDUSTRY 4.0 in PPC					
Sr. No	**Parent group**	**Readiness Factors**					
43	Technology	Requirement of Smart sensors in industry for implementation of INDUSTRY 4.0 in PPC					
44	Technology	Availability of Internet and Communication Technology in industry for implementation of INDUSTRY 4.0 in PPC					
45	Technology	Requirement of Data Governance system in industry for implementation of INDUSTRY 4.0 in PPC					
46	Technology	Evaluation mechanism of Data Readiness system in industry for implementation of INDUSTRY 4.0 in PPC					
47	Technology	Availability of Data Storage and Computing facilities for implementation of INDUSTRY 4.0 in PPC					
48	Technology	Availability of IT Integration software for implementation of INDUSTRY 4.0 in PPC					
49	Technology	Availability of IT Maturity systems for implementation of INDUSTRY 4.0 in PPC					
50	Technology	Evaluation mechanism of IT Readiness in industry for implementation of INDUSTRY 4.0 in PPC					
51	Technology	Availability of Complementary IT Systems in industry for implementation of INDUSTRY 4.0 in PPC					
52	Technology	Evaluation of ICT Readiness in industry for implementation of INDUSTRY 4.0 in PPC					
53	Technology	Requirement of Technology based Smart Products in industry for implementation of INDUSTRY 4.0 in PPC					

54	Technology	Requirement of integrating digital twins in industrial processing for implementation of INDUSTRY 4.0 in PPC					
55	Technology	Requirement of Digital Product Portfolio in industry for implementation of INDUSTRY 4.0 in PPC					
56	Technology	Requirement of Digitally-enabled Operations in industry for implementation of INDUSTRY 4.0 in PPC					
57	Technology	Requirement of Digitization of Product and Service Offerings in industry for implementation of INDUSTRY 4.0 in PPC					
58	Technology	Requirement of RFID Implementation in industry for implementation of INDUSTRY 4.0 in PPC					
59	Technology	Use of Analytical CRM Software in industry for implementation of INDUSTRY 4.0 in PPC					
60	Technology	Requirement of Employees having Remote Access to IT System in industry for implementation of INDUSTRY 4.0 in PPC					
61	Education	Requirement of Knowledge about technology in industry for implementation of INDUSTRY 4.0 in PPC					
62	Education	Requirement of knowledge about Method of production in industry for implementation of INDUSTRY 4.0 in PPC					
63	Education	Awareness of Benefits of technology in industry for implementation of INDUSTRY 4.0 in PPC					
Sr. No	**Parent group**	**Readiness Factors**					
64	Education	Requirement of Understanding the technology in industry for implementation of INDUSTRY 4.0 in PPC					

65	Education	Requirement of upgrading the Technical skills in industry for implementation of INDUSTRY 4.0 in PPC					
66	Education	Evaluation of Competencies in industry for implementation of INDUSTRY 4.0 in PPC					
67	Education	Requirement of enhancing digital skills in industry for implementation of INDUSTRY 4.0 in PPC					
68	Education	Requirement of Learning from Pilot project in industry for implementation of INDUSTRY 4.0 in PPC					
69	Education	Evaluating Employee skill sets in industry for implementation of INDUSTRY 4.0 in PPC					
70	Education	Mapping Skill acquisition in industry for implementation of INDUSTRY 4.0 in PPC					
71	Education	Building Team expertise in industry for implementation of INDUSTRY 4.0 in PPC					
72	Education	Evaluating level of awareness in industry for implementation of INDUSTRY 4.0 in PPC					
73	Education	Evaluating the qualification of work force in industry for implementation of INDUSTRY 4.0 in PPC					
74	Education	Assessing Information Connectivity Maturity in industry for implementation of INDUSTRY 4.0 in PPC					
75	Education	Requirement of Information-Seeking Skills in industry for implementation of INDUSTRY 4.0 in PPC					
76	Education	Acceptance and Application of New Technology and Media in industry for implementation of INDUSTRY 4.0 in PPC					
77	Education	Incorporating Information-Sharing Behaviour in industry for implementation of INDUSTRY 4.0 in PPC					

78	Education	Requirement of RFID Knowledge in industry for implementation of INDUSTRY 4.0 in PPC					
79	Education	Requirement of Employee Adaptability with Industry 4.0 in PPC					
80	Education	Knowledge and capability of Vertical and Horizontal Integration in industry for implementation of INDUSTRY 4.0 in PPC					
81	Education	Requirement of Operational Model in industry for implementation of INDUSTRY 4.0 in PPC					
82	Finance	Requirement of Calculating the Cost of technology for implementation of Industry 4.0 in PPC					
83	Finance	Requirement of calculating the Implementation cost for implementation of Industry 4.0 in PPC					
84	Finance	Requirement of introduction of Industry 4.0 in Financial KPI for implementation of Industry 4.0 in PPC					
Sr. No	**Parent group**	**Readiness Factors**					
85	Finance	Readiness of Finance and Investments related to implementation of Industry 4.0 in PPC					
86	Finance	Requirement of evaluating the Infrastructure and Equipment for implementation of Industry 4.0 in PPC					
87	Finance	Requirement of having a Share of revenues towards implementation of Industry 4.0 in PPC					
88	Finance	Requirement of calculating the Break even for implementation of Industry 4.0 in PPC					
89	Finance	Requirement of Financial aid given for implementation of Industry 4.0 in PPC					
90	Finance	Requirement of evaluation of Financial resources for implementation of Industry 4.0 in PPC					
91	Finance	Requirement of Funding strategy for implementation of Industry 4.0 in PPC					

92	Finance	Requirement of ICT(Information and Communication Technology) Infrastructure for implementation of Industry 4.0 in PPC					
93	Sales & Marketing	Requirement of Integrating Marketing Channels for implementation of Industry 4.0 in PPC					
94	Sales & Marketing	Requirement of accessing market and customer access for implementation of Industry 4.0 in PPC					
95	Sales & Marketing	Requirement of Multilevel customer interaction and customer profiling for implementation of Industry 4.0 in PPC					
96	Sales & Marketing	Requirement of Digital Marketing for implementation of Industry 4.0 in PPC					
97	Sales & Marketing	Requirement of Digital Media Awareness to customers for implementation of Industry 4.0 in PPC					
98	Capacity	Requirement of mapping the Variety of products in the industry for implementation of Industry 4.0 in PPC					
99	Capacity	Requirement of mapping Number of employees in the industry for implementation of Industry 4.0 in PPC					
100	Capacity	Requirement of mapping the turnover of industry for implementation of Industry 4.0 in PPC					
101	Capacity	Requirement of evaluating the Industry 4.0 Operations in PPC					
102	Capacity	Requirement of mapping the availability of Smart product and services in industry for implementation of Industry 4.0 in PPC					
103	Capacity	Requirement of checking the availability of Product Customization for implementation of Industry 4.0 in PPC					
Sr. No	**Parent group**	**Readiness Factors**					

104	Capacity	Requirement of Product and Process Integration for implementation of Industry 4.0 in PPC					
105	Capacity	Requirement of Autonomous processes for implementation of Industry 4.0 in PPC					
106	Capacity	Requirement of Mass production for implementation of Industry 4.0 in PPC					
107	Capacity	Capability of Process Transformation practices in industry for implementation of Industry 4.0 in PPC					
108	HR & Culture	Presence of Suggestions & Kaizen department in industry for implementation of Industry 4.0 in PPC					
109	HR & Culture	Incentives based on successful implementation of projects in industry for implementation of Industry 4.0 in PPC					
110	HR & Culture	Integration of the organizational structure in industry for implementation of Industry 4.0 in PPC					
111	HR & Culture	Requirement of assessment of Competitive pressures to change in industry for implementation of Industry 4.0 in PPC					
112	HR & Culture	Mapping Workforce with different ages in industry for implementation of Industry 4.0 in PPC					
113	HR & Culture	Mapping Employee adaptability with Industry 4.0 in industry for implementation of Industry 4.0 in PPC					
114	HR & Culture	Requirement of assessment of Empowerment in industry for implementation of Industry 4.0 in PPC					
115	HR & Culture	Mapping of Labour Market Obstructing Factors in industry for implementation of Industry 4.0 in PPC					
116	HR & Culture	Requirement of Professional Competence in industry for implementation of Industry 4.0 in PPC					
117	HR & Culture	Requirement of technology Proficiency in industry for implementation of Industry 4.0 in PPC					
118	HR & Culture	Requirement of assessment of Technical Competencies in industry for implementation of Industry 4.0 in PPC					

119	HR & Culture	Requirement of assessment of Learning Competencies in industry for implementation of Industry 4.0 in PPC					
120	HR & Culture	Requirement of evaluating Employees and Digital Culture in industry for implementation of Industry 4.0 in PPC					
121	HR & Culture	Requirement of Organization Employees Digital transformation in industry for implementation of Industry 4.0 in PPC					
122	HR & Culture	Requirement of Culture Strategic Alignment in industry for implementation of Industry 4.0 in PPC					
123	HR & Culture	Requirement of Innovation Culture in industry for implementation of Industry 4.0 in PPC					
Sr. No	**Parent group**	**Readiness Factors**					
124	HR & Culture	Requirement of Innovation Ecosystem in industry for implementation of Industry 4.0 in PPC					
125	HR & Culture	Assessment of Innovation Implementation Effectiveness in industry for implementation of Industry 4.0 in PPC					
126	HR & Culture	Global Measures of Organizational Readiness for Digital Innovation in industry for implementation of Industry 4.0 in PPC					
127	HR & Culture	Availability of Creativity Management in industry for implementation of Industry 4.0 in PPC					
128	HR & Culture	Availability of Idea Management in industry for implementation of Industry 4.0 in PPC					
129	Strategy	Availability of Leadership in industry for implementation of Industry 4.0 in PPC					
130	Strategy	Availability of Customer Centric approach in industry for implementation of Industry 4.0 in PPC					
131	Strategy	Mapping the Priorities in industry for implementation of Industry 4.0 in PPC					

132	Strategy	Involvement of all levels of Management in industry for implementation of Industry 4.0 in PPC					
133	Strategy	Availability of Decision making in industry for implementation of Industry 4.0 in PPC					
134	Strategy	Integration with Org Structure in industry for implementation of Industry 4.0 in PPC					
135	Strategy	Balance between tactical and Strategic goal in industry for implementation of Industry 4.0 in PPC					
136	Strategy	Requirement to Improve automation of individual or even all business processes in industry for implementation of Industry 4.0 in PPC					
137	Strategy	Requirement of Reengineering existing business models in industry for implementation of Industry 4.0 in PPC					
138	Strategy	Readiness of organizational strategy in industry for implementation of Industry 4.0 in PPC					
139	Strategy	Requirement of Partnership with INDUSTRY 4.0 Consultant in industry for implementation of Industry 4.0 in PPC					
140	Strategy	Requirement of having Smart factory in industry for implementation of Industry 4.0 in PPC					
141	Strategy	Requirement of Smart operations in industry for implementation of Industry 4.0 in PPC					
142	Strategy	Requirement of Smart products in industry for implementation of Industry 4.0 in PPC					
143	Strategy	Requirement of collaboration with expert in industry for implementation of Industry 4.0 in PPC					
144	Strategy	Creating Good preconditions in industry for implementation of Industry 4.0 in PPC					
Sr. No	**Parent group**	**Readiness Factors**					
145	Strategy	Requirement of Mass communication in industry for implementation of Industry 4.0 in PPC					

146	Strategy	Readiness Requirement specification to be highlighted in industry for implementation of Industry 4.0 in PPC					
147	Strategy	Presence of long term strategy in industry for implementation of Industry 4.0 in PPC					
148	Strategy	Requirement of evaluation of Business performance in industry for implementation of Industry 4.0 in PPC					
149	Strategy	Requirement of Strategic Readiness in industry for implementation of Industry 4.0 in PPC					
150	Strategy	Requirement of vertical with Strategy Innovation and Growth in industry for implementation of Industry 4.0 in PPC					
151	Strategy	Requirement of vertical with Strategy Management and Regulatory requirement in industry for implementation of Industry 4.0 in PPC					
152	Strategy	Requirement of linkage with Corporate Strategy in industry for implementation of Industry 4.0 in PPC					
153	Strategy	Requirement of vertical with Management Strategy and Organization in industry for implementation of Industry 4.0 in PPC					
154	Strategy	Requirement of HR Development Strategy in industry for implementation of Industry 4.0 in PPC					
155	Strategy	Requirement of Analysis and Strategy in industry for implementation of Industry 4.0 in PPC					
156	Strategy	Requirement of Market Strategy in industry for implementation of Industry 4.0 in PPC					
157	Strategy	Requirement of Business Strategy in industry for implementation of Industry 4.0 in PPC					
158	Strategy	Requirement of Strategy driven by Digital Vision in industry for implementation of Industry 4.0 in PPC					

159	Strategy	Requirement of evaluation of Smart Business Processes in industry for implementation of Industry 4.0 in PPC					
160	Strategy	Requirement of Road map Strategy in industry for implementation of Industry 4.0 in PPC					
161	Governance	Requirement of Regulatory pressure in industry for implementation of Industry 4.0 in PPC					
162	Governance	Requirement of Industrial Pressure in industry for implementation of Industry 4.0 in PPC					
163	Governance	Availability of Government influence in industry for implementation of Industry 4.0 in PPC					
164	Governance	Availability of Governmental support in industry for implementation of Industry 4.0 in PPC					
Sr. No	**Parent group**	**Readiness Factors**					
165	Supply Chain Management	Evaluation of digitization of supply chain in industry for implementation of Industry 4.0 in PPC					
166	Supply Chain Management	Availability of Smart product and services in industry for implementation of Industry 4.0 in PPC					
167	Supply Chain Management	Assessment of Supply chain constraints identification in industry for implementation of Industry 4.0 in PPC					
168	Supply Chain Management	Requirement of Supply Chain Integration in industry for implementation of Industry 4.0 in PPC					
169	Supply Chain Management	Assessment of Supply Chain Visibility in industry for implementation of Industry 4.0 in PPC					
170	Supply Chain Management	Assessment of Supply Chain flexibility in industry for implementation of Industry 4.0 in PPC					

171	Supply Chain Management	Evaluation of value chains and processes in industry for implementation of Industry 4.0 in PPC					
172	Supply Chain Management	Requirement of In time supply in industry for implementation of Industry 4.0 in PPC					
173	Supply Chain Management	Availability of Smart logistics in industry for implementation of Industry 4.0 in PPC					
174	Leadership	Requirement of Top management involvement and commitment in industry for implementation of Industry 4.0 in PPC					
175	Leadership	Requirement of Collaboration Network in industry for implementation of Industry 4.0 in PPC					
176	Leadership	Requirement of Innovation Management in industry for implementation of Industry 4.0 in PPC					
177	Leadership	Presence of change management in industry for implementation of Industry 4.0 in PPC					
178	Leadership	Requirement of Digital Practices in industry for implementation of Industry 4.0 in PPC					
179	Leadership	Requirement of Change Leadership in industry for implementation of Industry 4.0 in PPC					
180	Leadership	Requirement of Top Management Ability in industry for implementation of Industry 4.0 in PPC					
181	Leadership	Requirement of Top Management Commitment in industry for implementation of Industry 4.0 in PPC					
182	Leadership	Requirement of Top Management Involvement in industry for implementation of Industry 4.0 in PPC					

Form for finding out weights for normalized matrix for Delphi discussion

Readiness Factors	Capability	Stability	Networking	Information Technology advantage	Extent of auto correct	Ease of collaboration with new devices	Decision making	Extent of Data Exchange	Extent of forecasting	Extend of upgradation	Cost involved	Time for implementation
Requirement of Industrial Internet of Things (IIoT) in Industry for implementation of INDUSTRY 4.0 in PPC	VH	VH	MH	VH	VL	VH	VL	VH	L	VH	M	VL
Level of digitization of the organization for implementation of INDUSTRY 4.0 in PPC	L	M	VH	VH	M	VH	VH	VH	MH	VH	VH	VH
Digital Capabilities of the industry for implementation of INDUSTRY 4.0 in PPC	VH	VH	VH	VH	VH	VH	VH	VH	VH	VH	VH	VH
Capacity of Data Storage of the industry for implementation of INDUSTRY 4.0 in PPC	VH	VH	VL	M	M	VH	M	VH	VL	VH	VH	VL
Machine communication- Hardware component for implementation of INDUSTRY 4.0 in PPC	VH	VH	VH	VH	M	VH	VL	VH	VL	VH	H	VL
Requirement of Data Driven services in industry for implementation of INDUSTRY 4.0 in PPC	VH	VH	H	VH	VH	VH	VH	VH	VH	VH	VH	VH
Requirement of IOT platforms for implementation of INDUSTRY 4.0 in PPC	VH	VH	VH	H	VL	VH	VH	M	M	VH	VH	VH
Availability of Internet and Communication Technology in industry for implementation of INDUSTRY 4.0 in PPC	VH	VH	H	VH	VH	VH	VH	VH	VH	VH	VH	VH
Availability of IT Integration software for implementation of INDUSTRY 4.0 in PPC	VH	VH	H	VH	VH	VH	VH	VH	VH	VH	VH	M
Requirement of Knowledge about technology in industry for implementation of INDUSTRY 4.0 in PPC	M	ML	VL	H	VL	VL	VH	VH	VH	H	VL	VH
Requirement of Calculating the Cost of technology for implementation of Industry 4.0 in PPC	VH	VH	VL	VL	VL	VL	VL	VL	VH	VH	M	VH
Requirement of calculating the Implementation cost for implementation of Industry 4.0 in PPC	VH	VH	VL	VL	VL	VL	VL	VL	VH	VH	M	VH
Requirement of Financial aid given for implementation of Industry 4.0 in PPC	VH	VH	VL	VL	VL	VL	VL	VL	VH	VH	M	VH
Requirement of technology Proficiency in industry for implementation of Industry 4.0 in PPC	M	ML	VL	H	VL	VL	VH	VH	VH	H	VL	VH
Availability of Leadership in industry for implementation of Industry 4.0 in PPC	VH	VH	VL	VL	VH	VH	VH	M	VH	VH	M	VH
Presence of long term strategy in industry for implementation of Industry 4.0 in PPC	VH	VH	VL	VL	VH	VH	VH	M	VH	VH	M	VH
Requirement of Road map Strategy in industry for implementation of Industry 4.0 in PPC	VH	VH	VL	VL	VH	VH	VH	M	VH	VH	M	VH
Evaluation of digitization of supply chain in industry for implementation of Industry 4.0 in PPC	VH	VH	VH	VH	H	VH	VH	VH	VH	VH	VL	VH
Requirement of Top management involvement and commitment in industry for implementation of Industry 4.0 in PPC	VH	VH	VL	VL	VH	VH	VH	M	VH	VH	M	VH

Requirement of Collaboration Network in industry for implementation of Industry 4.0 in PPC	VH	VH	H	VH	VH	VH	VH	VH	VH	VH	VH	M
Presence of change management in industry for implementation of Industry 4.0 in PPC	ML	M	VH	VH	VH	VH	VH	VH	VH	VH	VH	VH

Readiness Factors	**Capability**	**Stability**	**Networking**	**Information Technology advantage**	**Extent of auto correct**	**Ease of collaboration with new devices**	**Decision making**	**Extent of Data Exchange**	**Extent of forecasting**	**Extend of upgradation**	**Cost involved**	**Time for implementation**
Requirement of Industrial Internet of Things (IIoT) in Industry for implementation of INDUSTRY 4.0 in PPC	VH	VH	MH	VH	VL	VH	VL	VH	L	VH	M	VL
Level of digitization of the organization for implementation of INDUSTRY 4.0 in PPC	L	M	VH	VH	M	VH	VH	VH	MH	VH	VH	VH
Digital Capabilities of the industry for implementation of INDUSTRY 4.0 in PPC	VH	VH	VH	VH	VH	VH	VH	VH	VH	VH	VH	VH
Capacity of Data Storage of the industry for implementation of INDUSTRY 4.0 in PPC	VH	VH	VL	M	M	VH	M	VH	VL	VH	VH	VL
Machine communication-Hardware component for implementation of INDUSTRY 4.0 in PPC	VH	VH	VH	VH	M	VH	VL	VH	VL	VH	H	VL
Requirement of Data Driven services in industry for implementation of INDUSTRY 4.0 in PPC	VH	VH	H	VH	VH	VH	VH	VH	VH	VH	VH	VH
Requirement of IOT platforms for implementation of INDUSTRY 4.0 in PPC	VH	VH	VH	H	VL	VH	VH	M	M	VH	VH	VH
Availability of Internet and Communication Technology in industry for implementation of INDUSTRY 4.0 in PPC	VH	VH	H	VH	VH	VH	VH	VH	VH	VH	VH	VH
Availability of IT Integration software for implementation of INDUSTRY 4.0 in PPC	VH	VH	H	VH	VH	VH	VH	VH	VH	VH	VH	M
Requirement of Knowledge about technology in industry for implementation of INDUSTRY 4.0 in PPC	M	ML	VL	H	VL	VL	VH	VH	VH	H	VL	VH
Requirement of Calculating the Cost of technology for implementation of Industry 4.0 in PPC	VH	VH	VL	VL	VL	VL	VL	VL	VH	VH	M	VH
Requirement of calculating the Implementation cost for implementation of Industry 4.0 in PPC	VH	VH	VL	VL	VL	VL	VL	VL	VH	VH	M	VH

Requirement of Financial aid given for implementation of Industry 4.0 in PPC	VH	VH	VL	VL	VL	VL	VL	VL	VH	VH	M	VH
Requirement of technology Proficiency in industry for implementation of Industry 4.0 in PPC	M	ML	VL	H	VL	VL	VH	VH	VH	H	VL	VH
Availability of Leadership in industry for implementation of Industry 4.0 in PPC	VH	VH	VL	VL	VH	VH	VH	M	VH	VH	M	VH
Presence of long term strategy in industry for implementation of Industry 4.0 in PPC	VH	VH	VL	VL	VH	VH	VH	M	VH	VH	M	VH
Requirement of Road map Strategy in industry for implementation of Industry 4.0 in PPC	VH	VH	VL	VL	VH	VH	VH	M	VH	VH	M	VH
Evaluation of digitization of supply chain in industry for implementation of Industry 4.0 in PPC	VH	VH	VH	VH	H	VH	VH	VH	VH	VH	VL	VH
Requirement of Top management involvement and commitment in industry for implementation of Industry 4.0 in PPC	VH	VH	VL	VL	VH	VH	VH	M	VH	VH	M	VH
Requirement of Collaboration Network in industry for implementation of Industry 4.0 in PPC	VH	VH	H	VH	VH	VH	VH	VH	VH	VH	VH	M
Presence of change management in industry for implementation of Industry 4.0 in PPC	ML	M	VH	VH	VH	VH	VH	VH	VH	VH	VH	VH

Prioritizing the factors

	DM1	DM2	DM3	DM4	DM5
Capability	M	I	M	I	VI
Stability	M	VI	VI	I	VI
Networking	UI	VI	I	M	I
Information Technology advantage	M	I	M	I	M
Extent of auto correct	VU	I	VU	UI	UI
Ease of collaboration with new devices	UI	UI	VU	VI	I

Decision making	UI	UI	VU	VU	M
Extent of Data Exchange	I	VI	M	VI	VI
Extent of forecasting	UI	UI	VU	VU	VU
Extend of upgradation	VI	I	UI	M	M
Cost involved	VI	VI	M	I	I
Time for implementation	I	I	I	M	VI

Fuzzy Set for Delphi Study

Variable	Rating scale	Fuzzy Scale
Strongly disagree	1	(0.0, 0.1, 0.2)
Disagree	2	(0.1, 0.2, 0.4)
Not Sure	3	(0.2, 0.4, 0.6)
Agree	4	(0.4, 0.6, 0.8)
Strongly Agree	5	(0.6, 0.8, 1.0)

The above Fuzzy set in Table 02 is derived from the Fuzzy Triangular Number Matrix in which rating scale from 1 to 5 describes from Strongly disagree to Strongly Agree with three vertices as Strongly disagree with 0.0, 0.1 & 0.2 Disagree with 0.1, 0.2 & 0.4 people with neutral reaction or not sure about the decision will have 0.2, 0.4 & 0.6, Agree stands for 0.4, 0.6 & 0.8 and Strongly Agree means 0.6, 0.8 & 1.0. These Fuzzy sets will replace the rating scale for further Fuzzy calculation.

Likert scale

EXPERT	**LIKERT SCALE**																
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**…**	**….**	**177**	**178**	**179**	**180**	**181**	**182**
1										--	--						
2										--	--						
3										--	--						
4										--	--						

5										--	--						
6										--	--						
7										--	--						
8										--	--						
9										--	--						
10										--	--						
11										--	--						
12										--	--						
13										--	--						
14										--	--						
15										--	--						
16										--	--						
17										--	--						
18										--	--						

The above Table represents the Likert scale in which 18 Decision makers were considered for fuzzy Delphi and their input against each readiness factors (all put together 182 readiness factors) were noted down in a tabulated column and given their rating scale as stated in Table-2, where Strongly disagree stands as 1, Disagree stands as 2, Not sure stands as 3, Agree stands as 4 and Strongly agree stands as 5

Linguistic variables-1

ABB	MEANING	MAGNITUDE	MAGNITUDE	MAGNITUDE
VH	VERY HIGH	0.83	1	1
H	HIGH	0.67	0.83	1
MH	MEDIUM HIGH	0.5	0.67	0.83
M	MEDIUM	0.33	0.5	0.67
ML	MEDIUM LOW	0.17	0.33	0.5
L	LOW	0	0.17	0.33
VL	VERY LOW	0	0	0.17

The above Fuzzy set in Table is the linguistic variables derived from the Fuzzy Triangular Number Matrix in which rating scale from VL to VH describes from Very Low to Very High with three vertices as Very Low with 0.0, 0.0 & 0.17 Low with 0.0, 0.17 & 0.33 Medium Low with 0.17, 0.33 & 0.5, Medium stands for 0.17, 0.33 & 0.5 and medium high means 0.5, 0.67 & 0.83, High stands for 0.67, 0.83 & 1 and Very high stands for 0.83, 1.0 & 1.0. These Fuzzy sets will replace the rating scale for further Fuzzy CoPrAs Method calculation for ranking among the most probable readiness factors which was identified by Fuzzy Delphi study

Linguistic variables-2

ABB	MEANING	MAGNITUDE	MAGNITUDE	MAGNITUDE
VI	Very Important(VI)	0.75	1	1
I	Important(I)	0.5	0.75	1
M	Medium(M)	0.25	0.5	0.75
UI	Unimportant(U)	0	0.25	0.5
VU	Very Unimportant(VU)	0	0	0.25

The above Fuzzy set in Table is the linguistic variables derived from the Fuzzy Triangular Number Matrix in which rating scale from VI to VU describes from Very Unimportant (VU) to Very Important with three vertices as Very Unimportant with 0.0, 0.0 & 0.25 Unimportant with 0.0, 0.25 & 0.5 Medium Important with 0.2, 0.5 & 0.75, Important stands for 0.5, 0.75 & 1.0 and Very Important means 0.75, 1.0 & 1.0. These Fuzzy sets will replace the rating scale for further Fuzzy CoPrAs calculation for finding out the parameters to rate the 21 most probable readiness factors.

Criteria selected for the assessment of Catalyst

Criteria	Criteria ABB	Short description
Technological Readiness	C1	Technology needs to be analyzed for its readiness for implementing Industry 4.0 in any Industry
Technology security	C2	Online platforms where data needs to be secured for any business related data transfer
Organizational readiness	C3	Organization update for incorporating new technology and internet based readiness for any industry
Financial commitment	C4	Having required budget and commitment from senior management for implementation of Industry 4.0 projects

Criteria selected for the assessment of Impediments

Criteria	Criteria ABB	Short description
Budgetary approval process	I1	Budget approval process should not be lengthy and time taking
Implementation timeline	I2	Implementation timeline should be mapped and forecasted before project initiation
Leadership	I3	Involvement of senior leadership is required
Organizational readiness	I4	Organization update for incorporating new technology and internet based readiness for any industry

TFN for ISM calculation

TRIANGULAR NUMBER	VARIABLE	SYMBOL
0.75,1,1	VERY STRONG	AR.
0.5,0.75,1	STRONG	SR
0.25,0.5,0.75	RELATIVELY	FR
0.0,0.25,0.5	WEAK	LR
0,0,0.25	VERY WEAK	UN

Structural self matrix for Catalysts

		Competitive edge	ROBOTS	Application	Business KPI	IOT based system	Digitization	Connectivity	Leadership
	FACTORS	8	7	6	5	4	3	2	1
Leadership	1								
Connectivity	2								
Digitization	3								
IOT based system	4								
Business KPI	5								
Application	6								
ROBOTS	7								
Competitive edge	8								

Structural self matrix for Impediments

		Budget allocation	High-fi level knowledge building	Central Data ownership	Integration with existing networking	High labour volume	IT prerequisite	Low level leadership	Inhouse talent	Forecasting immediate return
	FACTORS	9	8	7	6	5	4	3	2	1
Forecasting immediate return	1									
Inhouse talent	2									
Low level leadership	3									
IT prerequisite	4									
High labour volume	5									
Integration with existing networking	6									
Central Data ownership	7									
High-fi level knowledge building	8									
Budget allocation	9									

List of Publications

S. No	Type of Paper (Journal Paper /Conference proceeding/ Book Chapter)	Name of the Journal/ Conference/Book	Jounal indexing (Scopus/UGC/Web of Science)	Title of the Paper	Published Date (Date/ Month/Year)	Volume & Issue Number	ISSN/ISBN Number	Impact Factor/ SJR	Type of paper (Research/ Review)	Whether this is thesis work or not (Yes/ No)	Web link of journal indexing	Log Request ID
1	Journal Paper	Journal of Theoretical and Applied Information Technology	Scopus	Multi linear regression-based iot and fog com	15-10-2023	Vol.101. No 19	ISSN: 1992-8645 E-ISSN: 1817-3195		Research	YES	WIP	

				puting on maintenance predictions approach for efficient asset management in industry revolution 4.0								

List of Conferences attended

Sr. No	Title of the Conference	Name of the Conference	Date	International/ National
1	Building Resilient Industry by Competency Augmentation	International Conference on Commerce, Management & Interdisciplinary Subjects (ICCMIS)	28-10-2021 to 29-10-2021	International
2	To identify and analyse the readiness of PPC 4.0 with Delphi and Fuzzy CoPrAs method	Neo Business Practices for the Evolving World (SYMBIOSIS INSTITUTE OF BUSINESS MANAGEMENT, NAGPUR)	04-04-2022 to 06-04-2022	International