OPTIMIZING SEMICONDUCTOR PACKAGING OPERATIONS THROUGH BUSINESS INTELLIGENCE: A COLLABORATIVE APPROACH FOR SKILL DEVELOPMENT IN INDIA

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ABSTRACT

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This study aims to identify and examine the critical business skills necessary for success in the ever-evolving field of semiconductor manufacturing in packaging. This study explores the important business and technical skills needed for success in the fast-changing field of semiconductor manufacturing, with a focus on packaging operations in India. As Industry 4.0 continues to impact the manufacturing sector, companies must combine technical know-how with strong business decision-making. The research examines how tools like Business Intelligence (BI) and Big Data Analysis (BDA) can help improve processes by collecting real-time data, reducing production defects and improving product quality.

The Indian semiconductor packaging industry is growing quickly and faces the challenge of keeping up with global standards. As Industry 4.0 technologies transform manufacturing, combining technical expertise with strong business decision-making has become essential.

Surveys and questionnaires were distributed to professionals in the semiconductor packaging sector to gather data on current skill levels, training needs and adoption of Industry 4.0

technologies. Combining open-ended and close-ended questions helped capture numerical data and detailed opinions.

The study also highlights the role of Industry 4.0 technologies, such as IIoT with Artificial Intelligence (AI), Machine Learning (ML) and automation, in making manufacturing smarter and more efficient for better data handling, smarter decision-making and fewer errors in production.

A significant focus of the research is the need for workforce training. Employees need the right skills to use new systems and tools effectively, so companies must invest in training programs focusing on digital skills and data use.

In addition, the thesis underlines the importance of collaboration between industry and academic institutions, which can help develop skilled talent, drive innovation and support the digital transformation of India's semiconductor sector.

Overall, this research provides practical insights and a future-ready plan for improving backend semiconductor packaging operations by aligning it with technology adoption, skill development and strategic planning. The study offers a clear path toward long-term growth and global competitiveness for India's semiconductor industry.

Keywords: Smart manufacturing, operations, skill development, semiconductor packaging, India, Industry 4.0, business skills, business intelligence.

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INTRODUCTION

1.1 Introduction

Focus on the Semiconductor sector in India

The growing demand for electronics in India is the main reason behind the growth of the country's semiconductor sector. To support this, the government has set up semiconductor production clusters Policy Circle, (2025), providing incentives such as tax rebates, subsidies and investing more in research and development (R&D).

While India excels in semiconductor research and design, particularly in software and embedded systems, its domestic manufacturing capabilities remain underdeveloped, especially in semiconductor chip production.

Although India has established itself as a leader in semiconductor R&D, the country continues to rely heavily on imports for essential components like integrated circuits. This dependency has created a significant gap in meeting the growing demand for semiconductors in India post-pandemic, mainly in the areas of electronics, automotive, healthcare and telecommunications. To address this issue, the Indian government has introduced initiatives like ‘Make in India’ (Information Technology and Innovation Foundation (ITIF), (2024) and created policies under the National Policy on Electronics (NPE) (Ministry of Electronics and Information Technology MeitY (2019) to encourage local production.

These initiatives aim to make India a hub for Electronic System Design and Manufacturing (ESDM), leveraging the country's potential to become self-sufficient in semiconductor production. Ministry of Electronics and Information Technology, (2022) Despite these efforts, India's semiconductor manufacturing is still behind other countries. India currently produces only 11% of the world's semiconductors and depends heavily on foreign suppliers for most of its needs states World Economic Forum, (2022). The disruption of global semiconductor supply chains, especially during the COVID-19 pandemic, exposed the weaknesses in India's supply chain according to Business Standard, (2021). Industries like the automotive sector faced major production delays because of a shortage of essential semiconductor parts. This highlights the urgent need to boost domestic semiconductor production, especially the upcoming backend packaging production, to maintain economic stability and remain competitive globally.

As India aims to address these challenges, the role of technological innovation cannot be overstated. As India works to tackle these challenges, technological innovation plays a very important role. The new advanced technologies such as BDA, AI and BI have the potential to greatly improve efficiency, lower costs and improve product quality. However, successfully adopting these technologies requires more than just technical infrastructure. It necessitates the development of a skilled workforce capable of effectively leveraging Business Intelligence (BI), Big Data Analytics (BDA) and smart manufacturing tools.

There is a gap between what the semiconductor industry needs and the skills taught in Indian education. A skilled workforce is necessary to make the most of new technologies. To address this, industry and academic institutions need to work closely together. India can create a skilled workforce by combining education with industry needs and encouraging continuous skill development as per the article in TeamLease Degree Apprenticeship (2024). This will help the country stay competitive in the global semiconductor market.

This thesis explores how India can accelerate its semiconductor sector's growth by integrating technological innovation, skill development and industry-academia collaboration. It focuses specifically on the optimisation of semiconductor packaging operations through the application of BI and BDA technologies.

The study will examine how these technologies can help address key challenges, such as resource optimisation, fault detection and skill gaps within the workforce.

1.2 Research Problem

The fast-growing semiconductor industry in India, driven by new technology and the rising demand for efficient electronic devices, brings several challenges, especially in semiconductor packaging. The ICs packaging is crucial because it directly affects the power, performance of electronic devices which are used in every electronic gadget, device or systems. The advance India has is its young and skilled workforce, coupled with its growing electronics sector, which positions the country as a potential semiconductor powerhouse, but key obstacles remain according to TeamLease Degree Apprenticeship, (2024). These include insufficient manufacturing capacity, a lack of workforce preparedness and the limited integration of digital transformation technologies quotes Times of India (2024).

The semiconductor manufacturing industry faces persistent challenges in optimizing production efficiency and minimizing downtime due to complex supply chains, frequent equipment failures, the facilities, infrastructure and the need to comply with strict industry regulations. While the potential of Business Intelligence (BI) tools in improving operational efficiency is well recognized, there remains a gap in understanding how BI can be effectively integrated at various stages of semiconductor production. Specifically, there is a lack of empirical research on how BI tools can be utilized for real-time monitoring, predictive maintenance and data-driven decision-making within the semiconductor packaging process.

Another important factor is the successful use of Business Intelligence (BI) technologies in semiconductor manufacturing, which relies on having a skilled workforce that can operate these advanced tools and understand their impact. However, there is a clear gap between the skills needed in the industry and those taught in academic training programs. As the semiconductor sector in India strives to expand and modernise, the need for a workforce proficient in both emerging technologies and the semiconductor industry's specific requirements becomes increasingly important.

Thus, the problem extends beyond technological integration and includes the critical skill development issue.

The semiconductor industry in India faces a problem where the skills taught in academic institutions don't match the practical, technical skills needed. This skill gap makes adopting Business Intelligence (BI) tools harder and successfully transitioning to digital manufacturing.

This research, therefore, aims to investigate the use of BI in Semiconductor packaging by studying both the technology and human resources. This thesis will look at how Business Intelligence (BI) tools can help improve efficiency, reduce downtime and ensure that regulations are followed. It will also focus on the need for better collaboration between industry and academic institutions to close the skills gap. The research aims to provide practical ideas on how the semiconductor industry in India can use BI technologies effectively. It will also explore how educational institutions can update their courses to better prepare students for the skills needed in the industry. This research aims to provide practical insights on how the semiconductor industry in India can effectively use BI technologies and how educational institutions can adjust their programs to better prepare workers for these new demands.

1.3 Purpose of Research

Research and development has received the lion's share of funding, but that hasn't been enough to tackle the sector's massive problem as per Semiconductor Industry Association (SIA), (2023) There must be a lot more cooperation between supply and demand side players and a more thorough set of measures and funding programs.

The chip scarcity's effect on the Indian economy has shown how critical it is to respond quickly. As per Ajit Manocha, (2025). concrete effort including all necessary public and commercial sectors must immediately begin to capitalize on strengths, diversify capabilities, fill structural gaps, enter new markets and forge international alliances.

Skill development is seen as an important agenda after COVID-19, when we see several International and National players gearing up for large-scale manufacturing worldwide. as per The Economic Times (2023), the market's need for faster operating speeds and increased functional density pushes semiconductor package designers to create more complex packaging to meet the demand. India's semiconductor sector seeks talent in areas like industrial automation, PCB design, IT hardware and packaging, but academic engagement and collaboration with businesses are crucial for driving domestic R&D and fostering innovations.

The purpose of this study is to explore the integration of Big Data Analytics (BDA) and Business Intelligence (BI)in optimizing semiconductor packaging processes in India.The research focuses on how BI and BDA tools can help identify inefficiencies, reduce downtime and support real-time fault detection, data driven decision making and failure analysis. It explores how these technologies can improve key factors such as production speed, product qualityand defect reduction, which are essential for maintaining competitiveness in the global market.

Over and above, the research emphasises the importance of skill development and training to ensure that workers are equipped to fully use BI and BDA tools. It discusses how workforce training—both within semiconductor companies and through partnerships with academic institutions—can provide the skills needed for the successful adoption of these technologies. The study highlights that adopting smart manufacturing solutions requires a combination of technical knowledge, business understandingand the ability to adapt to digital changes.

The research also explores how collaboration between academia and industry can help create a talent pool that meets the changing needs of The study focuses on how technical training, business knowledge digital skills are connected. It aims to provide practical suggestions for improving educational programs and workforce development to better meet the needs of the industryThe study also examines the challenges that Indian semiconductor companies face, such as poor infrastructure, limited resources and the need for a clear strategy to incorporate digital tools into their existing manufacturing processes.

In conclusion, the research supports the growth of a sustainable and adaptable packaging industry by encouraging the adoption of new technologies and the development of the necessary skills.

The study's goal is to ensure that the workforce is ready to support the upcoming semiconductor packaging industry and move towards long-term success in the global market.

1.4 Significance of the Study

India is seen as a key position as an alternative to China, which makes it more evident that skill development is needed to meet the requirements of the manufacturing industry standards. As per the government announcements, as per The Economic Times, (2023) as India moves forward to establish itself as a semiconductor manufacturing hub, the industry will create demand for 1.2 million jobs across the sector as manufacturing evolves and design functions solidify further, said Jaya Jagadish, Country Head of AMD Indiaand Chairperson of the Semicon Talent Building Committee.Tech GIG, (2023), Kumari R, (2023).

This research focuses on the effects of digital data analysis on business intelligence abilities relevant to semiconductor packaging in India. To facilitate a smooth shift towards DT-BIS-SP, there is a focus on developing and implementing training programs to improve the skills of the Indian workforce. This research focuses on the effects of creating a BI perspective for semiconductor packaging that the IIoT backs on skill development. It examines the consequences of forming multidisciplinary teams and introducing a responsive IIoT-BI-SP system to deal with problems in the ever-changing semiconductor sector.

This study offers strategic insights for semiconductor manufacturers seeking to introduce advanced digital technologies for their operations. It also provides academic institutions and policy-makers recommendations to reform technical education ensuring alignment with emerging industry needs. The research aims to contribute to the growth of a competitive and innovation-ready semiconductor ecosystem in India and beyond by highlighting the dual impact of technology adoption and workforce development.

1.5 Research Purpose and Questions

The primary objective of this research is to examine the role of Big Data Analytics (BDA), Business Intelligence (BI)and digital transformation technologies in enhancing semiconductor packaging processes in India. The purpose of this research is to assess the preparedness of the workforce in the semiconductor packaging sector for the ongoing digital transformation driven by technologies such as Business Intelligence (BI) and Big Data Analytics (BDA). The study aims to find key skill gaps, assess how much digital knowledge employees currently haveand see how ready they are to adapt to new technologies. By surveying workers in the industry, the research will look at both the strengths and challenges the workforce faces in adopting smart manufacturing practices.

This study also looks at how these findings can impact training programs, policiesand the use of BI and BDA technologies in the semiconductor industry. It will explore how companies can close skill gaps and improve their workforce skills to make the shift to Industry 4.0 easier. This shift is expected to help improve production efficiency, reduce defectsand make better decisions. The study focuses on how collaboration between universities and industry can help connect what students learn in school with what is needed in the workplace. It also highlights the importance of continuous learning, improving skillsand using new technologies to support growth and make the semiconductor industry more competitive.

Through this investigation, the research will provide actionable insights into the alignment of workforce skills with the demands of digital transformation, supporting the design of targeted upskilling initiatives and policy recommendations to drive the successful integration of digital tools in semiconductor packaging processes.

Research Questions

1. In what ways can the integration of Business Intelligence (BI) and Business Decision Analytics (BDA) optimise operational efficiency, improve decision-making processes and enhance quality control within semiconductor packaging operations in India?

2. What are the key skill gaps within India's semiconductor packaging workforce and how can strategic collaborations between academia and industry bridge these gaps to cultivate a workforce capable of supporting smart manufacturing initiatives?

This thesis investigates the relationships between Business Intelligence (BI), Business Decision Analytics (BDA), talent development and digital transformation technologies within India's backend semiconductor packaging industry. It presents a comprehensive framework for understanding how these elements can address workforce skill gaps, enhance operational efficiency and foster innovation in smart manufacturing.

CHAPTER II:

REVIEW OF LITERATURE

2.1 Theoretical Framework

This assessment aims to identify and examine the critical business skills necessary for success in the ever-evolving field of semiconductor manufacturing. The abstract looks at the most important skills required for part of the ecosystem be it successful leadership, strategic decision-making and long-term development, emphasizing the complementary nature of technological know-how and commercial aspects for organizations including universities to prepare the people or students to be industry ready. The study synthesizes existing information to provide a strategic road map for people and organizations hoping to succeed in the ever-changing world of manufacturing, drawing on real-life examples and industry insights. This research emphasises the value of technological progress and the need for realize business skills for navigating and capitalizing on the possibilities given by high-end manufacturing. This paper goes deeply into the essential business abilities necessary for the success of semiconductor manufacturing with in-depth examination. A strategic blend of technical expertise and commercial perspective is essential. Important skills like strategic planning, supply chain optimisation, digital literacyand agile project management will be studied in detail. Extensive research is summarized here to assist industry experts, educatorsand legislators with a starting point for navigating the ever-changing landscape in the field of high tech semiconductor manufacturing.

Keywords: Semiconductor Manufacturing, Industry 4.0, business skills, business intelligence, leadership.

The primary purpose of this review is to ascertain if there is compelling evidence that efforts to teach and develop the workforce for semiconductor manufacturing have had this result. What became apparent in the process of this review, however, was that several subsidiary problems must first be answered before the problem of evaluating the effectiveness of the process can be approached. The second of these problems is whether the movement has a common knowledge of “semiconductor manufacturing.” The third problem might be formulated thus: is “semiconductor manufacturing” generalizable or is it tied to subject matter? The fourth problem is whether adequate evaluative measures of critical thinking are available to measure the effectiveness of efforts to check the skills, knowledge and business competencies. Answering these prior questions is essential before inquiring whether there is compelling evidence that teaching this high tech subject results in a transfer of skills or dispositions that students can use in other arenas and gain knowledge to be placed. This line of inquiry supplies the structure for this to see how a business requirement for manufacturing of semiconductor packaging can be addressed.

Hence, these objectives will provide main strength to this research study.

2.2 Theory of Reasoned Action

The Theory of Reasoned Action (TRA) serves as important factor to understand the area, the product and the task to be performed keeping in mind several factors.

A paradigm shift toward smart manufacturing is reshaping the production environment in today's age of fast technology innovation. The development of Industry 4.0 is bringing state-of-the-art technology like automation, the Internet of Things (IoT)and artificial intelligence (AI) into traditional production (Bongomin et al., 2020) While technical expertise is crucial, a company's ability to navigate, capitalize onand maintain the advantages of smart manufacturing is just as important. The primary purpose of this review is to ascertain if there is need to teach the subject and technical knowledge in terms of bringing up talent, innovation and commercial aspects towards the semiconductor manufacturing. What became apparent in the process of this review, however, was that several subsidiary problems must first be answered before the problem of evaluating the effectiveness including smart manufacturing and technology transfer can be approached. This introductory section lays the groundwork for thoroughly examining the business competencies necessary for manufacturing success (Mezgebe et.al, 2023), (Corallo, A, 2022). The success of high scale manufacturing depends on more than just technological aspects; it also requires the capacity to balance innovation with well-informed commercial practices. This analysis sheds light on the many facets of business abilities that are becoming more important in the fast-paced, smart manufacturing environment (Qu Y, 2021). We want to define the core skillsets needed by people and businesses to flourish in this age of unparalleled technology integration by analyzing industry trends, case studiesand the opinions of experts (Antonazzo, 2023).

In essence, this paper that the convergence of BI and skill development, fueled by Big Data Analytics, represents a comprehensive strategy for empowering smart manufacturing in semiconductor packaging. As the industry stands on this transformative journey, embracing these integrated strategies an imperative for those seeking these in the fast-paced and competitive landscape of semiconductor packaging (Hsu, C. Y., Chen, 2020) (Lei, X., et al, 2022).

As engaged in this investigation, the symbiotic tie between technology breakthroughs and commercial understanding becomes clear. The key to achieving efficiency, competitivenessand sustainable development is to acquire the newest technology and orchestrate it intelligently (Zangiacomi, 2020), (Heidemann Lassen., 2021). This review seeks to contribute useful insights to experts, legislatorsand scholars by examining the intricate interactions of business skills within the setting of manufacturing, thus enabling an in-depth awareness of the set of competencies necessary to negotiate the difficulties and benefits of potential in the rapidly developing innovative manufacturing environment (Qu Y, 2021). Still, in reality, business understanding is crucial for the smooth execution of such initiatives (Antonazzo, 2023). The phrase "business skills" is used here to refer to a broad set of abilities that go much beyond the narrower realm of technical expertise in production. To get the best results, businesses need to take a strategic and comprehensive approach to using technology, ensuring that innovation is in lockstep with their overall goals (Schaupp,S, 2020),(Sharma R 2022).

2.3 Human Society Theory- Culture as Important Factor to Technology Adoption

Culture is important when it comes to regional conditions and technology absorbed, it plays an important role in respective regions in leading a project. in semiconductor manufacturing, leadership is one of the most important business abilities. Leaders in this field need to see the big picture and understand the revolutionary possibilities of new technology while motivating their people to accept and welcome that future (Jones A., et al., 2020), (Contreras-masse, et al., 2020). Equally important is the ability to make strategic decisions, which requires an understanding of the big picture and the ability to embrace technologies, optimize processes to advance the organization's mission (Feng, Y, et al., 2020). Furthermore, flexibility and agility are crucial managerial abilities for manufacturing because of how quickly technology changes, organizations need to be flexible in their approach and methods. This calls for an in-depth familiarity with market tendencies, consumer preferencesand the state of the industry as a whole (Jones, A. Et al., 2020), (Contreras-masse, et al., 2020).

Good communication helps build a more cohesive and cooperative workforce by keeping everyone in the loop about new technologies and how they may be used (Popescu, G. H et al., 2020). Business acumen in finance is another important talent in manufacturing. It entails conducting cost-benefit evaluations, building sustainable financial models to support long-term developmentand comprehending the monetary consequences of technological investments (Opazo-Basáez, M.,et al., 2023). This explanation illustrates the complicated interaction between technology improvements and business abilities in the area of manufacturing. By establishing these abilities, firms can negotiate the intricacies of the shifting environment, position themselves for sustainable success (Throne, O., et al, 2020), (Horick, C, 2020).

Source: author

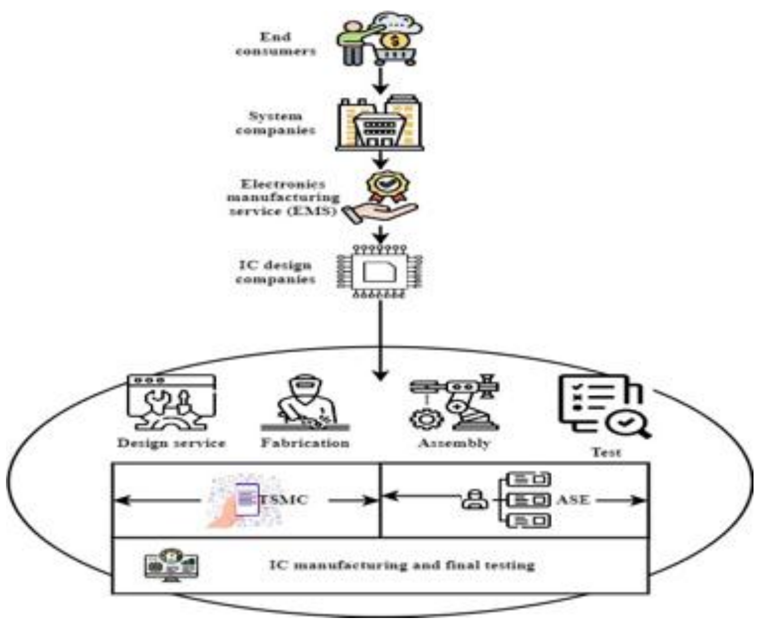

Figure 2.1:
Value chain of semiconductor manufacturing

As a technical enabler and multiple-lever driver for the whole electronics value chain, the semiconductor sector is generally acknowledged as a critical driver of economic development. As shown in Figure 2.1, a semiconductor company's integrated circuit (IC) is a part of other parts or finished goods. Demand uncertainty has been a major problem for the semiconductor industry, which is located upstream in the integrated circuit supply chain (Brown et al., 2000). It is difficult to predict the exact demand from end users thus businesses in the supply chain often keep a little extra stock on hand. The demand fluctuation becomes more pronounced as one moves down the supply chain from the end-consumer to SM and testing firms. Fabrication of the wafer, probing of the wafer, assembly and final testing are the four main components of Semiconductor Manufacturing (SM).

The analytical role in optimizing inventory levels, enhancing supplier relationships and guaranteeing a continuous flow of commodities is emphasised in the BI literature when it comes to supply chain management. Businesses that package semiconductors may use business intelligence tools to reduce costs and lessen the effect of supply chain interruptions by making procurement choices based on data. A well-managed supply chain is crucial for semiconductor production to remain competitive on a worldwide scale, which is in line with this strategic application of BI.

The literature also emphasises how BI has revolutionized innovation in semiconductor packaging. Business intelligence (BI) helps find places to enhance processes and develop technology by encouraging a data-driven decision-making culture. To drive ongoing innovation in semiconductor packaging technologies, researchers stress the significance of creating business intelligence capabilities inside enterprises. This will allow organizations to use the data that is fully accessible to them. The literature on semiconductor packaging and business intelligence concludes that the latter has several positive effects on the sector. Businesses in the semiconductor packaging industry are finding that business intelligence (BI) is an essential tool for managing the challenges of contemporary production in areas such as real-time monitoring, quality control, supply chain optimisation and innovation. The incorporation of BI systems is anticipated to assume a more and more crucial role in molding the future of semiconductor packaging as technology progresses.

Working in semiconductor manufacturing plants requires smart business skills since these abilities help the sector run efficiently, innovate and adapt. Data interpretation and comprehension are of the utmost importance. Workers need strong data analysis skills to make judgments based on trends discovered in manufacturing process data. An individual's total performance may be enhanced by data literacy-enabled problem-solving, process optimisation and well-informed decision-making. Competence in the use of computer programs, hardware and automation systems as they pertain to the production of semiconductors. Experience with MES (Manufacturing Execution Systems), CAD (Computer-Aided Design) software and other digital platforms unique to the sector is required.

Source: author

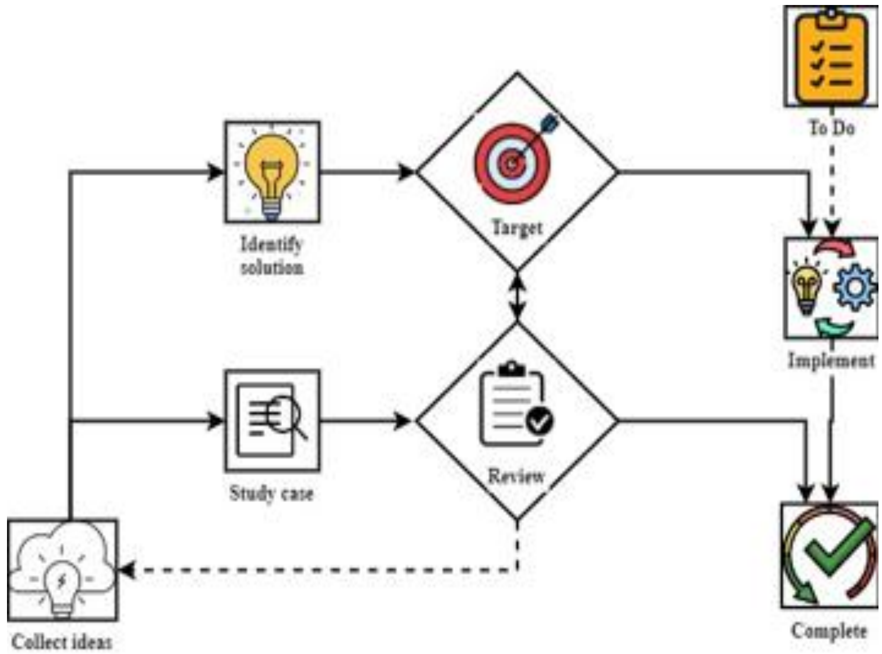

Figure 2.2:
Smart business skills for manufacturing factories

Figure 2.2 shows that a digitally connected industrial environment benefits from increased efficiency, fewer mistakes and improved cooperation made possible by digital literacy.

When it comes to solving problems and improving operations in manufacturing, this expertise is crucial. Improving overall productivity, decreasing faults and avoiding downtime are all outcomes of fast and efficient problem solving which is required. The ability to work well with others is essential for navigating the many departments and roles present in a manufacturing setting. Working together as a team and being able to see things from other people's points of view are all part of this. Working together guarantees a comprehensive approach to problem-solving, speeds up decision-making and boosts creativity. It is crucial to have an attitude of constant learning. Maintaining a skilled and competitive staff requires a culture that can adapt to change.

Competence in effectively arranging, coordinating and carrying out tasks. As part of this process, objectives are defined, resources are distributed and progress is tracked. The smooth execution of manufacturing processes, meeting deadlines and optimisation of resources are all guarantees of effective project management. To guarantee that goods fulfil or surpass industry requirements, it is important to comprehend and execute quality control procedures. Knowledge of Total Quality Management (TQM) concepts is part of this. Keeping to high-quality standards is essential for staying competitive in the semiconductor industry, satisfying customers and complying with regulations. Excellent verbal and written communication abilities including the capacity to explain complex ideas to audiences with varying levels of technical knowledge. Ensuring correct information is delivered across the business, reducing mistakes and facilitating cooperation are all outcomes of good communication. As a leader, one should be able to steer teams in the right direction, make sound strategic choices and encourage a creative and supportive work environment. Inspiring teams, generating organizational success and navigating the tough semiconductor business environment all need strong leadership. A strong grasp of business and manufacturing ethics, the ability to make judgments in accordance with these principles and the promotion of an honest and trustworthy work environment. A blend of technical knowledge, flexibility, teamwork and a dedication to lifelong learning is required to develop astute business acumen in the semiconductor manufacturing industry.

Source: author

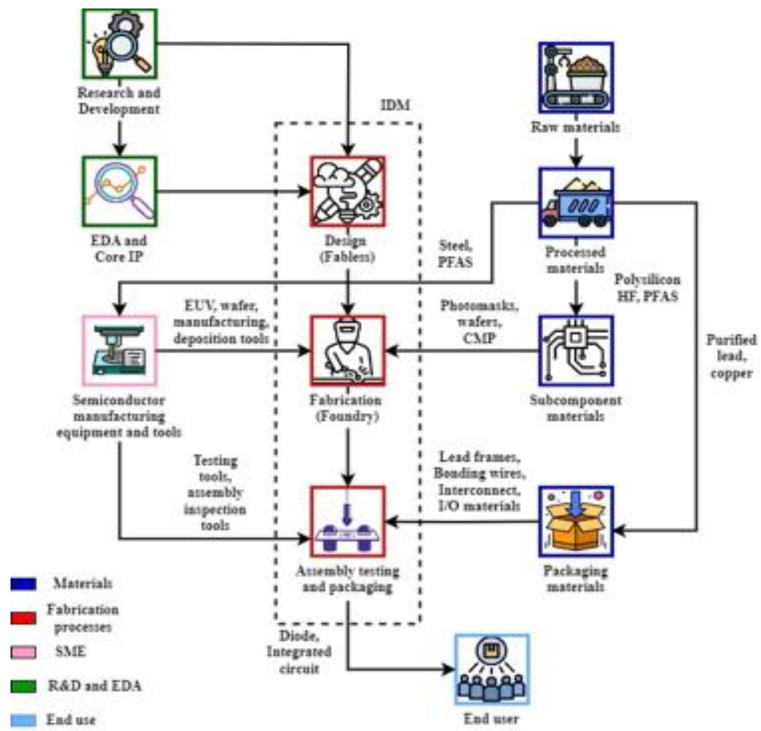

Figure 2.3:
Semiconductor manufacturing and packaging with BI systems

Figure 2.3 shows the needs fixing and make sure the company's plans are in line with what the industry considers ideal. In order to maximize efficiency in the production and packaging of semiconductors, business intelligence tools are crucial. The semiconductor industry is changing at a quick pace, but with the help of data analytics and visualization tools, businesses can keep up with the changes, make better choices and increase efficiency and quality.

A common thread running across the semiconductor supply chain is the problem of not having enough production capacity to fulfil consumer demand. Renewable energy sources, electric cars, personal devices, data center sand even military weaponry rely on semiconductors. Approximately two-thirds of the worldwide market value of conventional semiconductors is attributable to applications in computing and communication; the remaining one percent is split evenly between industrial and automotive usage. The industry is at risk due to many vulnerabilities that researchers have identified. From 26% in 1995 to a pitiful 10% in 2020, the United States' proportion of the world's semiconductor production capacity plummeted Tech GIG, (2023), . This is happening despite the fact that demand has reached historic highs; since 2010, the global adoption of goods based on semiconductors has doubled every three years. Semiconductors are essential to the development of AI and other cutting-edge computer technologies, in addition to their use in energy applications and EVs. Advanced testing and packaging (ATP), design, manufacturing and assembly are the three primary steps in the manufacture of semiconductors. Although several companies often work together, the paper notes that a single entity, such as an integrated device maker, might handle the whole process. While American semiconductor designers are unrivalled, their country lags far behind in many other domains, like fabrication, material supply, ATP and packaging. The study suggests funding research and development of gallium nitride (GaN) and silicon carbide (SiC) Wide Bandgap (WBG) devices for use in utility-scale renewable energy systems with higher voltage applications. This highlights the need to improve the efficiency and performance of WBG devices made in the United States to counteract the import of devices based on silicon. To achieve a target of doubling energy efficiency every two years for the next twenty years, the paper also suggests investing in traditional semiconductor R&D, demonstration and commercial applications.

New technical advancements are made approximately every three years. Training for domestic workers is also necessary. The problem is to see whether adequate evaluative measures of a skilled workforce are available to measure the effectiveness of efforts to teach the processes involved in the manufacturing and business analysis. Answering this prior question is essential before inquiring whether there is compelling evidence that results in a transfer of skills or dispositions that people or students can use in other arenas. This line of inquiry supplies the structure for this review of the relevant literature.

The semiconductor packaging and manufacturing industries rely heavily on business intelligence (BI) solutions to improve overall performance, decision-making capabilities and efficiency. Collect information on the production and packaging of semiconductors from a variety of sources. For a complete picture of operations, combine data from sensors, quality control systems, production equipment and the supply chain. Follow the production of semiconductors as it happens in real-time. A business intelligence dashboard showing production, quality and equipment status Key Performance Indicator (KPIs) should be implemented. This makes it easy to see problems and ways to fix them quickly. Examine information on production metrics, rejects and faults using business intelligence tools. To prevent quality problems from happening, use predictive analytics to find them in advance. Efficiently and affordably, optimize the supply chain for semiconductors. Make use of business intelligence tools to assess and enhance logistics, supplier performance and inventory management. Because of this, the production and packaging operations can go without a hitch. Reduce maintenance expenses and equipment downtime. To anticipate equipment breakdowns, set up predictive maintenance models with the help of business intelligence technologies. This allows for preventative maintenance, which in turn decreases unscheduled downtime and increases overall equipment effectiveness (OEE). Raise production efficiency throughout the board. Examine manufacturing records for inefficiencies and bottlenecks. Reduce cycle times and boost productivity by optimizing manufacturing processes using insights generated by business intelligence.

To put it another way, this data is useful for fixing problems and preventing them from happening again. Maintain conformity with all applicable industry and government regulations. Achieve regulatory compliance with the help of business intelligence tools. Produce audit paperwork and reports to prove compliance with quality and safety regulations. Find the best way to divide resources and keep expenses in check. Monitor and control production expenses, energy use and resource utilization with the help of business intelligence analytics. Making well-informed decisions on techniques to reduce costs is made possible by this. Encourage a mindset of always seeking ways to enhance production procedures. BI systems provide analytics for measuring and tracking performance over time. It would help if you looked into BI insights on a regular basis to see where you can make improvements and then make those adjustments. Evaluate results in relation to market norms. Make use of business intelligence tools to evaluate critical performance indicators against market standards.

Comprehensive survey

Focusing on the modern period (2000-2020), (Mohammed M A et al., 2020) investigated the skills of successful technical management and the role of technological leaders in sustaining smart manufacturing (SSM). The research also shows that sustainability is an essential objective of the fourth industrial revolution. Although both the scientific community and business have been interested in smart SM and business 4.0 in recent years, there has not yet been an effort to analyse the state of these emergent concepts. Finally, the study's findings will aid in recruiting capable leaders and enhancing leadership programme development inside business.

To foster creativity during the digital transition, (Giudice. M C et al. 2021) investigated how businesses are becoming more agile, flexible and polyglot having different languages. Industry 4.0 enablers and smart companies are often linked to "digital innovation" nowadays. While large corporations across various industries have welcomed the innovations above, prior studies have indicated that small and medium-sized businesses (SMEs) have mostly adopted them in manufacturing. Small and medium-sized businesses (SMEs) are the focus of this paper, which shows a good balance of exploitation and investigation as well as impressive agility in identifying and studying the digital systems that SMEs use to function and grow in response to outside influences.

The development of a dynamic capability-based methodology for evaluating the maturity of intelligent manufacturing transformations, as (Tzu-Chieh Lin et al., 2021) discovered. The first step is to examine how different maturity models relate to the capacity to handle dynamic situations. This discovery suggests that most maturity models cannot detect an organization's emotional ability, much alone analyse it in a changing, competitive market. Our dynamic capability-based counsel helps businesses re-evaluate their strategy and build the skills they need to adapt to a volatile business climate.

(Jung-Sing Jwo et al., 2021) examines the human-in-the-loop for digitalization challenges and provide a 3Is (Intellect, Interaction and Interface) component for factories in order to improve the adoption of smart technology and achieve the smart manufacturing objective. The Intellect feature is meant to impart expertise to the production machinery. The emphasis of this fact is on the partnership between factory workers and their machines. The interface focuses on how people may best use artificially intelligent technology to facilitate two-way communication with production machinery. The paper makes claims about the concepts themselves and shows how they might be used in practice via various specific case studies.

In order to fix problems and enhance operations in real-time, the production line's digital infrastructure collects and interprets data from many monitoring sensors. The flexibility and complete traceability of this line are revolutionary. Change management, a lack of talent, the need for innovative business models and the need for rethought products are only a few of the difficulties that have been overcome.

To effectively develop an innovative culture inside a business, (Guzmán. et al., 2020) advocate strong leadership. Therefore, leaders take on an increasingly important function as we move towards the paradigm shift of Industry 4.0. In light of Industry 4.0, this review seeks to outline critical leadership abilities. Leadership and Industry 4.0 literature was a major source for this research. The study linked the four categories of leadership competency—cognitive, interpersonal, business and strategic—to ten leadership qualities relevant to Industry 4.0. In preparation for the transition to Industry 4.0, companies may think these skills are essential for their future executives.

Differences between conventional and smart factories were identified in a study conducted by (Kalsoom. T., et al, 2020). Manufacturing firms and supply chains cannot achieve optimal performance without access to advanced, low-cost sensor technology. The study provides an agenda for future research that includes the active growth of smart manufacturing plants inspired by Industry 4.0 principles and it highlights several sensors employed in automated manufacturing.

Researchers (Won JY., et al., 2020) looked from the dawn of the fourth industrial revolution forward and the company has placed a premium on information technology as a means to increase its production capabilities.

(Fernando E. García-Muiña et al., 2020) investigated the impact on the company's selling point of shifting from a traditional to a sustainable business model. The findings represent the sustainable value proposition of the new organization concerning the environment, economics and society. This article can potentially serve as a resource for other manufacturers as they work to develop their sustainable business models. This research examines the existing literature on implementing eco-friendly business strategies in practical settings.

(Lee H et al. 2023) merged revenue and intellectual data of applicant enterprises in the smart manufacturing sector into a panel dataset at the company level for the years 2010-2015. As a result of merging distinct technical fields, convergent technology can revolutionize several industries and improve many more. The statistics show a U-shaped relationship between company diversification and financial performance in the early phases of the convergence paradigm. For managers, this study's findings on the overlapping paradigm's method of handling innovation are very relevant.

2.4 Literature survey based on traditional modelling:

Semiconductors are projected to play an increasingly important part in India's economy; thus, researchers have proposed a big data (BD) study of the country's imports and exports of the commodity (Tejasri, B., et al., 2023). A key component of the Fourth Industrial Revolution, the semiconductor business is expected to keep expanding as the COVID-19 epidemic propels the non-face-to-face economy forward. This research uses import/export microdata to classify semiconductor imports and exports by type, quantity, destination country and local region; it then evaluates India's involvement in the worldwide supply chain for semiconductors and related equipment.

(Tan, C. L., et al., 2023) suggested important ideas, including collecting business intelligence, exchanging information and knowing the state of assets and IT, were proposed to assess the industry visibility of block chain (BC). In light of this emerging field, this research will examine the connections between supply chain performances (SCP), block chain visibility and supply chain integration (SCI) in the semiconductor industry during the DT era. To better prepare for the future of semiconductor supply chain management (SCM) in the DT era and utilize block chain technology, policymakers might refer to this study's conclusions.

An innovative variety-based Integrated Feeding Control Strategy (IFCS) was created to lessen the cost of production-stage equipment changes (Xie, F., et al., 2021). The number of clusters in a certain category is constrained by the algorithm, which is set to match the number of kinds of production capacity in the process. Based on the average input-output of the semiconductor, the clustering is then used to determine the kinds and amounts of production via an integrated feeding strategy. Lastly, the proposed method's effectiveness and superiority are backed by experimental data.

(Hariharan, A. N., et al., 2021) suggested to estimate the factors that have led to rising export income over the previous almost three decades, the selected variables are used in conjunction with an empirical model of regression analysis (RA). Over the last two decades, India's quality of living has risen with its GDP as the world has come to recognize the Indian subcontinent as a center for an abundance of trained technical labour. Because of this, the pool of qualified workers has grown regional and sub-regional service output. This regression research has provided quantitative evidence for the most important factors driving regional economic growth.

The study optimizes and enhances production line management by using an intelligent computer approach, as described in (Li, Z., et al., 2021) streamlining the process from product adoption to final shipment of production lines requires intelligent technology, which in turn improves production quality, reduces production costs and increases the efficiency of general equipment. Modern manufacturing technology enables manufacturers to automate and flexibly deliver batch items, allowing them to better adapt to changes in customer demand.

The process optimisation strategy aims to increase output from the manufacturing floor while minimising waste. The primary objective of the research (Tripathi, V., et al, 2022) is to enhance industrial sustainability via the creation of an intelligent production management system and the recommendation of an efficient process optimisation strategy that can tackle the specific challenges faced on the factory floors of Industry 4.0. Experts in the field and students alike would benefit from the article's proposed production management system, which they believe will improve operational excellence and facilitate shop floor management for heavy equipment manufacture in the era of Industry 4.0.

The article (Gajdzik, B., et al., 2022) proposes a framework of employee abilities and competencies that may be used to create job descriptions for workers in organisations shifting to Industry 4.0. The theoretical section was formulated based on an analysis of the current scientific literature and practical studies into the competency of the workforce during the fourth industrial revolution. This case study looked at a steel mill's smart manufacturing architecture, including the metallurgist's requisite abilities and skills. This section will examine the characteristics of a creative and inventive Operator 4.0 and Industry 4.0 worker. (Park I.B et al.., 2021) introduced a Deep Reinforcement Learning-based (Deep-RL) scheduling approach for semiconductor packaging facilities, where an agent centrally assigns jobs to machines. Extensive studies on large-scale datasets show that the suggested technique requires much less computing time than the algorithms while outperforming methods based on rules and other RL techniques concerning makespan.

In a study carried out at 130 °C and 85% RH for semiconductor packages, (Kim M.S et al., 2021) suggested microstructural features of the Ultrasonic Bonding Surfaces (UBS). These attributes' pre- and post-HAST versions have been contrasted to the original ones. Also, the Kirkendall voids, obstacles to Au-Al interdiffusion, were minimized by the Ag-Au-Al IMC at the ACA wire contact.

To include chipsets in HPC applications in semiconductor packaging techniques, (Lee. L.C. et al., 2021) used a new High-Density Fan Out (HDFO) technology. Results show that compatibility of multi-layer stacked materials (Si, Cu, PI, shaping molecules and under fills) has a crucial influence on warpage control at the wafer, fan-out component and packaging stages.

(Wang. Y et al., 2021) came up with a new way to package semiconductor packaging lasers: with cooling on both sides. The simulation findings demonstrated that both sides of the air conditioner reduced the semiconductor's top temperature from 48.5℃ to 40℃.

According to (Sahoo. K et al., 2021), a systems architect needs guidance in selecting the physical layer (PHY) most suited for inter-die interaction for processors and languages. This paper details a method of optimisation and cost function that considers the crucial electrical, wrapping and production factors that influence the choice of physical equipment (PHY). A processor-memory design scenario is then evaluated using it.

To fully understand the aspects that contribute to the success and sustainability of smart manufacturing projects inside enterprises, it is vital to systematically examine crucial business competencies required for the profitability of smart production. This kind of study is conducted to shed light on the skills and knowledge businesses need to succeed in the age of smart manufacturing

Table 2.1 shows the above-mentioned literature with its advantages and disadvantages.

Source: author

Sl. No	Reference	Title	Agreement	Disagreement
1	Alharbi, M. (2022).	Engineering Leadership and Sustainable Smart Manufacturing: Literature Review with Focus on Contemporary Era (2000-2020)	The analysis found that most studies aimed to improve engineering leadership by teaching non-technical skills to new engineers.	The scientific and business communities have recently become more interested in smart SM and Industry 4.0. Still, there has been little effort to critically examine the status of these two paradigm shifts in the literature.
2	Del Giudice et. al. (2022)	A self-tuning model for smart manufacturing SMEs: Effects on digital innovation	Multiple cross-level analyses, fresh ideas and concepts from various fields and an overt acknowledgement of digital technologies' influence on reshaping organizations and	Opinions on the 'on demand' responsiveness of innovative production SMEs are a special area where research on self-tuning businesses is lacking, which looks to be the actual problem

			societies are all necessary for a full grasp of digital transformation.	regarding international competitiveness.
3	Lin, T. C., Sheng et. al. (2021)	Dynamic capabilities for smart manufacturing transformation by manufacturing enterprises	The research addresses a knowledge gap in the literature by including a dynamic capacity in the maturity model evaluation used by the Singapore Economic Development Board. The model was created for empirical analysis and to identify the relevance of important skills along with the variables that influence them.	Since resource-based theory focuses on analysing resources without considering how those resources are generated, it cannot completely explain how businesses might improve their technical prowess to keep their competitive edge in an ever-changing market.
4	Ghobakhloo, M. (2020).	Determinants of information and digital technology	Based on the opinions of an expert panel in smart manufacturing,	The smart manufacturing phenomena and academic interest in it are still in

		implementation for smart manufacturing	the next step is to use Interpretive Structural Modelling (ISM) to draw links between the supplementary components.	their early stages; the resulting clutter is understandable.
5	Jwo, J. S (2021)	Smart technology-driven aspects for human-in-the-loop smart manufacturing	The interface focuses on how people may best use artificially intelligent technology to facilitate two-way communication with production machinery.	Protecting proprietary information or consumer data, for example, maybe a real headache if they fall into the wrong hands.
6	Moshiri, M., Charles et. al. (2020)	An industry 4.0 framework for tooling production using metal additive manufacturing-based first-time-right smart manufacturing system	The ability to decentralize production to sites closer to clients or materials suppliers, which is more convenient, is another advantage of a completely digitalized	When adopting a process chain in line with Industry 4.0 concepts, mind-set is especially important because, even if the equipment works perfectly, the system can still fail if the people using

			modular system, which can be managed remotely from the headquarters.	it aren't prepared to deal with the change.
7	Guzman, V. E et. al. (2020)	Characteristics and skills of leadership in the context of industry 4.0	The digital industrial revolution can boost manufacturing systems' adaptability, mass customization, production speed, product quality and output.	Changing and intervening in processes at any stage of value creation has the danger of throwing off the equilibrium of the chain of production, which may be very costly.
8	Arcidiacono, F et. al. (2022)	The role of absorptive capacity in the adoption of smart manufacturing	Prerequisites for managers include familiarity with both traditional and modern information technology, as well as an understanding of how to use SM to accomplish organizational	In many cases, substantial effort and money are needed to develop absorptive ability. It could be challenging for small and medium-sized firms (SMEs) to allocate enough resources to acquire and maintain responsive capability.

			objectives effectively and the ability to develop knowledge through practices aimed at equipping senior managers with SM competencies; all contribute to a company's propensity for acquiring and assimilating SM knowledge.	
9	Kalsoom, T et. al. (2020)	Advances in sensor technologies in the era of smart factory and industry 4.0 †	Researchers have studied the connection between several optimum control models and a smart industrial system based on Industry 4.0.	Limitations in accessible technologies might also result from a lack of worker skills and manufacturer technical willingness. There is a lack of research that deals with these concerns.
10	Won, J. Y et. al, (2020)	Smart factory adoption in small and medium-	Local small and medium-sized	The field of smart factories has grown

		sized enterprises: empirical evidence of manufacturing industry in Korea.	enterprises (SMEs) have not adequately responded to the government's various policies and financial support. This is the primary motivation for doing this investigation.	rapidly since 2010, but scholars have yet to agree on a common definition of the word or the factors that influence or are affected by its widespread adoption. Research on firms, especially those of a medium or smaller scale, is uncommon.
11	García-Muiña, et. al. (2020)	Sustainability transition in industry 4.0 and smart manufacturing with the triple-layered business model canvas	This research intends to provide the groundwork for further studies on sustainable business model development, operational innovation of business models in industrial contexts and the integration of sustainability into corporate strategy.	While many studies have examined the environmental impact of various business model implementations, few have explored sustainability's economic and social dimensions from a "triple bottom line" vantage point.

12	Lee, H. (2023).	Converging technology to improve firm innovation competencies and business performance: evidence from smart manufacturing technologies	Using a resource-based perspective, this research examines how convergent technologies have altered the connection between company diversity and firm success. Thus, in the context of smart manufacturing convergence, it highlights the mechanism that causes the influence of converging technologies on diversification performance.	On the one hand, this shift has added uncertainty for companies that have expanded into uncharted technical or commercial territories due to internal skill shortfalls.

Table 2.1
Comparison table between existing works

Importance of literature on Business Intelligence of Semiconductor Packaging:

When companies in the semiconductor packaging sector use business intelligence (BI) techniques to analyze data, generate reports and gain strategic insights, it improves the quality of decisions made by those companies. According to the research on BI in semiconductor packaging, it is crucial for boosting innovation, enhancing product quality and optimizing operational efficiency. Integrating BI systems with semiconductor production processes is one important element that has been discussed in the literature. Scientists stress the need to monitor and analyse data produced by packaging processes in real-time. Production metrics, failure rates and equipment performance may be better understood with this connection, which allows for proactive decision-making. Semiconductor packaging plants may improve their overall equipment effectiveness (OEE) and decrease downtime by using business intelligence (BI) to pinpoint inefficiencies, forecast maintenance requirements and simplify operations

Through the literature review, we can conclude that when companies in the semiconductor packaging sector use business intelligence (BI) techniques to analyse data, generate reports and gain strategic insights, it improves the quality of decisions made by those companies. In semiconductor packaging, BI is crucial for boosting innovation, enhancing product quality and optimizing operational efficiency. Integrating BI systems with semiconductor production processes is one important element that has been discussed in the literature. Scientists stress the need to monitor and analyse data produced by packaging processes in real-time. This connection may better understand production metrics, failure rates and equipment performance allowing for proactive decision-making. Semiconductor packaging plants may improve their overall equipment effectiveness (OEE) and decrease downtime by using business intelligence (BI) to pinpoint inefficiencies, forecast maintenance requirements and simplify operations.

When it comes to optimizing yield and quality control, the literature also stresses the importance of BI. Companies in the semiconductor packaging industry may find trends in the incidence of defects using sophisticated analytics. This allows them to analyse the causes and implement targeted solutions when the people are well informed and well trained in this field. This dedication to quality control is in line with the industry's aim of providing dependable, high-performance semiconductor products, the leadership roles and skills are important and necessary.

Gap Analysis on Skill Development for Semiconductor Packaging

Stakeholders in India's semiconductor packaging technology sector may benefit from a comprehensive gap analysis in three ways: future strategy planning, increased competitiveness and industrial development, which are not covered in this research.

A semiconductor boom might soon be upon India. (Jaydeep Saha, 2023) in his article, Talent 101 predicts that by 2025, the world's industries will require over a million trained workers. An analysis released by the Semiconductor Industry Association (SIA) in collaboration with Oxford Economics projects a gap of 1.4 million skilled workers in the US economy and a shortage of 67,000 in the semiconductor industry alone by 2030 (The Economic Times, 2023)

During Prime Minister Narendra Modi's June US visit, Micron Technology announced an $825 million investment. Applied Materials and Lam Technologies are investing an additional $400 million to educate sixty thousand engineers in India. The semiconductor sector in India is seeing rapid growth, leading analysts to think that the country has the potential to address the talent gap. Prime Minister Narendra Modi announced plans to provide specialist semiconductor courses at more than 300 prestigious schools throughout India during the Semicon India 2023 conference in July of this year.

In this dynamic landscape, integrating smart manufacturing strategies has become a pivotal force for ensuring competitiveness and sustainability Gaardboe, R et al, (2018). This paper delves into the synergistic combination of Business Intelligence (BI) and skill development initiatives, empowered by Big Data Analytics, to users in a new era of efficiency and innovation in semiconductor packaging (Verma, A., et. al, 2019).

Semiconductor packaging plays a central role in the final stages of semiconductor production, influencing electronic device performance, size and functionality. As the industry adopts smart manufacturing principles, incorporating BI becomes imperative for informed decision-making (Richardson, J., et al, 2020). Manufacturers can optimize processes, identify bottlenecks and proactively address issues by leveraging BI, leading to enhanced productivity and reduced time-to-market (Abusweilem, M. et al, 2019). (Rauch, et al., 2019).

There are almost 8,000 unfilled vacancies in the semiconductor industry, spanning a wide range of job profiles and levels, according to data collected by Team Lease EdTech for Money control (Abhishek Sahu,2023), Semiconductor industry has 8,000 active jobs, mainly in entry-level positions).. Numerous employment and advancement possibilities exist within the semiconductor sector. There is a need for every skill set, from the ability to design complex circuits to the ability to supervise production processes.

Key employment prospects include, according to Professor Sankaran Aniruddhan, Associate Professor in the VLSI Group at the Indian Institute of Technology Madras's Department of Electrical Engineering:

- People who create electronic systems.
- Creators of embedded systems.

- System testing engineers.
- Electronics hardware experts.
- Engineers specializing in projects.
- Developers of semiconductors.
- Engineers specializing in certain applications.
- Electronics research engineers.

An undergraduate degree (B.Tech.) in an electrical, computer, or communication engineering-related discipline is required.

The first step is earning a B.Tech. in electrical engineering, electronics and communication engineering, or a closely related discipline. Microelectronics and very large-scale integration (VLSI) design are areas of expertise taught at a few Indian colleges. According to the report by a professor of electronics and communications engineering at NIIT University, "graduates can pursue a master's degree (M.Tech) in microelectronics or VLSI to gain further expertise in the field" after finishing a B.Tech. More over software developers may find work building libraries and applications for these chips at the International Institute of Information Technology Hyderabad (IIIT Hyderabad) at the Center for VSLI and Embedded Systems Technology. When silicon manufacturing is brought to India, there will soon be a need for students with expertise in production chemistry and industry.

In the mid-1970s, the United Nations Development Programme (UNDP) launched a support initiative with the Central Electronics Engineering Research Institute (CEERI), Pilani, to enhance semiconductor technological skills via targeted courses. The Centre for Scientific and Industrial Research was the lab's parent organization. "It will launch a joint initiative to map capacity, identify vulnerabilities and bolster supply-chain security for semiconductors and their vital components." That same year, in September 2021, the Quad bloc, which consists of India, the United States, Japan and Australia—issued a joint declaration.

India has just announced semiconductor technology partnerships among the Quad nations. A semiconductor ecosystem that supports manufacturing, R&D, design, talent development and supply-chain resilience was to be created by India and Japan, according to a memorandum of cooperation signed on July 20. The Centre announced this year's debut of a short-term certificate course in semiconductor manufacturing in June for Semiconductor Technologies (SemiX) at IIT-Bombay in collaboration with Applied Materials India Private Limited and Global Foundries. Lam Research, an American semiconductor component, engineering and services provider and the Indian Institute of Science (IISc) launched a pilot program to teach semiconductor fabrication engineers in India in July.

According to News18, the All India Council for Technical Education approved 80 more schools to offer VLSI semiconductors as an undergraduate major in July. Specifically, students would learn about design, logistics and cutting-edge communication technologies. AICTE introduced two new semiconductor design and production programs on February 18th of this year. Graduates of these programs would be qualified for a wide range of jobs and get financial incentives to pursue them. Upskilling is an additional option for students in addition to full-time studies. Starting in the fall of 2019, students and professionals from India can enroll in semiconductor programs at Purdue University. This training and upskilling initiative will be launched in collaboration with the India Semiconductor Mission (ISM) and will last 6-12 months. In preparation for the most recent Semicon India conference, a memorandum of understanding (MoU) addressing this matter was signed.

Using public block chain technology, (Magdy.M et al., 2023) were able to resolve the supply chain (SC) issue of the bullwhip effect in the semiconductor industry.

2.4 Summary of the Chapter:

Finally, this comprehensive study has led the fundamental business competencies necessary for the success of manufacturing in today's semiconductor packaging industrial environment. The dynamic age of smart manufacturing characterized by the ubiquitous impact of Industry 4.0 requires integrating cutting-edge technology with well-informed business skills as a cornerstone for success. This report highlights leadership as critical for directing businesses toward technology integration. Collaboration and communication skills play a crucial role in allowing the smooth integration of smart technology across multiple organizational departments and external relationships. Effective communication guarantees a common knowledge of goals and the creation of a collaborative work culture, which is especially important as smart manufacturing in semiconductor packaging expands beyond the constraints of conventional silos. This research highlights the importance of financial understanding in guaranteeing efficient resource allocation and the creation of long-term financial models. Long-term success in the smart production environment requires an in-depth knowledge of the economic consequences of technology investments and the completion of extensive cost-benefit evaluations. It is becoming clearer that a comprehensive and strategic strategy is necessary for the success of manufacturing as we negotiate the complex interaction between technology and business abilities. The companies that successfully grow and combine these essential business talents will shape the future of manufacturing in semiconductor packaging. Professionals, politicians and academics may use the insights gained from this research as a road map to realize the full potential of smart production for long-term economic growth.

CHAPTER III:

METHODOLOGY

3.1 Overview of the Research Problem

The semiconductor industry plays an important role in the global technology, with innovations in different sectors such as electronics, automotive, telecommunication and healthcare. The semiconductor industry in India is at a turning point, driven by fast-paced technological advancements for smaller, faster and more efficient devices worldwide. Within this industry, semiconductor packaging is a critical process that directly influences the performance, reliability and overall success of semiconductor devices. However, despite the rapid growth and technological advancements in the semiconductor sector, the production faces challenges such as inefficiencies in production, product quality and limited real-time data integration, particularly in emerging markets like India.

This research aims to address these challenges by investigating the potential of integrating Business Intelligence (BI), Big Data Analytics (BDA) and the Industrial Internet of Things (IIoT) into the semiconductor packaging process. This research looks at how using Business Intelligence (BI), Big Data Analytics (BDA) and the Industrial Internet of Things (IIoT) can help improve semiconductor packaging. The goal is to make operations more efficient, improve decision-making and strengthen quality control. These technologies can also help businesses cut costs, use resources better, and stay competitive by reducing waste, increasing output, and lowering downtime.

This chapter outlines the research design, methodology, data collection techniques and analytical tools used in the study. Given the dual focus on technological implementation (BI and BDA) and workforce development, a mixed-methods approach was adopted, combining both quantitative and qualitative data. This enabled a comprehensive understanding of both measurable outcomes (e.g., production efficiency, skill gap percentages) and stakeholder perceptions (e.g., academic and industry insights).

3.2 Operationalization of Theoretical Constructs

This study gives useful ideas for semiconductor companies looking to modernize using data-based technologies. It also provides recommendations for colleges and government bodies to improve technical education so it matches the needs of the industry. From a business point of view, the study shows how these technologies can help reduce costs, use resources efficiently and improve product quality. This can lead to more profit and a stronger position in the market. This approach helps both the industry and education sectors, giving business leaders the tools they need to succeed in a rapidly changing tech world.

In semiconductor packaging, Business Intelligence (BI) systems are very important for making good decisions. By using data visualization, analysis and collection, BI systems help manufacturers improve operations, manage production data and control quality. These systems are key to smart manufacturing because they give insights that make processes more efficient and reduce mistakes.

Big Data Analytics (BDA) is also important in semiconductor packaging. It helps by analysing large amounts of data to find patterns, predict machine problems and suggest ways to improve operations. This helps companies make better decisions faster, which is crucial for smart manufacturing.

The findings from this study show that it’s important to give workers the right technical training to use BI and BDA systems properly. Although knowing the theory is important but it is not enough; workers also need practical experience with these tools. Partnerships between schools and industries are important for closing the gap between theoretical learning and real-world application. This will help prepare workers for the challenges of smart manufacturing.

Digital Transformation (DT) uses advanced technologies like automation and the Industrial Internet of Things (IIoT) to make production processes smoother and more efficient. When combined with BI and BDA systems, these technologies improve real-time data processing, flexibility and overall production efficiency.

BI and BDA work well together in semiconductor packaging. By combining these systems, companies can make decisions in real-time, improve equipment efficiency (OEE)and improve packaging processes. However, these systems need skilled workers to use them properly. This is why it's important to have formal training programs for workforce to manage these technologies.

Collaborations between schools and industries are key to encouraging continuous learning, making sure that workers are always learning new skills for smart manufacturing and automated production. As digital technology keeps changing, using BI and BDA in semiconductor packaging becomes even more important. This means workers need to constantly update their skills to help companies stay competitive.

Literature Review**:**

This thesis looks at existing research to understand the current state of semiconductor packaging, especially how Industry 4.0 technologies like IIoT are used. The review also focuses on why it's important for workers in this field to keep learning new skills to keep up with changing technologies. The sources used include academic journals, industry reports and case studies examining how digital transformation, business intelligence and semiconductor packaging manufacturing work together. The Theory of Reasoned Action (TRA) provides a useful strategy for understanding how beliefs, attitudes and intentions influence behaviours, particularly relevant in the semiconductor manufacturing industry as the industry embraces smart manufacturing technologies—such as automation, AI and IIoT. The Theory of Reasoned Action (TRA) helps us understand how beliefs, attitudes and intentions affect behaviours, especially in the semiconductor manufacturing industry. The theory shows how both individual and company attitudes toward new technologies can influence their decision to invest in skill development and adopt new tools.

In the context of semiconductor packaging, this paper argues that the integration of Business Intelligence (BI), Big Data Analytics (BDA) and skill development is crucial for the success of smart manufacturing. However, achieving this shift requires more than technical expertise; it requires a strategic combination of technical and business knowledge. This integration of technological adoption and workforce development is essential for driving efficiencies, improving operational performance and staying competitive in the global market.

Theoretical Framework

The theoretical framework for this study is based on the concept of Industry 4.0 and its key components: Big Data Analytics (BDA), Business Intelligence (BI) and the Industrial Internet of Things (IIoT). These technologies are seen as essential methods for digital transformation in semiconductor packaging. This study highlights the importance of skill development for the adoption of innovative technologies.

i. Digital Transformation Industry 4.0:

Industry 4.0 is about integrating advanced technologies like BDA, BI and IIoT to improve manufacturing processes. Ghobakhloo (2020) explains that these technologies help improve efficiency, but to make the most of them, companies also need to be ready and willing to change. This aligns with this study as it examines how semiconductor manufacturers in India can integrate these digital tools to make their processes more efficient and productive.

ii. Technology Integration in Semiconductor Packaging:

The framework also looks at how BDA, BI and IIoT can improve semiconductor packaging. These technologies can help improve production efficiency, decision-making and quality control. This is similar to the work done by Opazo-Basáez et al. (2023), who looked at how organizations need to have the right mix of technology and skilled workers to successfully adopt smart manufacturing. Their study supports this research's goal of figuring out how semiconductor companies can integrate these technologies and address the skills gap in the workforce.

Other studies, like those by Won et al. (2020) and Verma et al. (2019), also help explain how these technologies have worked in other industries. Their research shows how BDA, BI and IIoT improve manufacturing, which is relevant to this study's aim of understanding how these tools can benefit semiconductor packaging.

iii. Skill Development and Workforce Readiness:

An important part of the theoretical framework is the idea that skill development is key for overcoming challenges in adopting new digital technologies. According to Opazo-Basáez et al. (2023) and Guzmán et al. (2020), even the best technologies will fail if the people using them don't have the right skills. This supports this study's focus on bridging the gap between current workforce skills and the skills needed for Industry 4.0. The framework suggests that training programs are essential to help workers adapt to new technologies.

Creswell (2014) also supports this approach, suggesting that mixed-methods research (including both quantitative and qualitative data) is useful for studying both technology and human factors. This is exactly what this study is doing: gathering data on technology use and understanding the workforce's readiness to adopt these technologies.

iv. Organizational Culture and Adoption of Digital Technologies:

The framework discusses the role of organizational culture and leadership in adopting Industry 4.0. Guzmán et al. (2020) stresses that leadership plays an important role in organizational change for adopting advanced digital tools. Similarly, Arcidiacono et al. (2022) emphasize the importance of a company's ability to absorb and use new knowledge effectively. This means that organizations need to have the right culture, leadership and structure to adopt and use new technologies successfully.

This study builds on these ideas by looking at how leadership and organizational culture affect the adoption of BDA, BI and IIoT in semiconductor packaging. Arcidiacono et al. (2022) argue that companies that are good at absorbing new knowledge are better at adopting new technologies, which directly relates to the goals of this study.

Linking the Theoretical Framework to Research Objectives:

This theoretical framework connects directly to the objectives of this study. This study is looking at how digital technologies (BDA, BI, IIoT) can improve semiconductor packaging and how workforce development can support this digital transformation. By using insights from established research, like that of Ghobakhloo (2020), Opazo-Basáez et al. (2023) and others, this study is building a solid theoretical base. This framework helps explain why the focus is on both the technology side and the human side (skills development) of the industry 4.0 transformation in the semiconductor industry.

Alignment with the previous studies:

This theoretical framework uses ideas from previous studies on Industry 4.0, digital transformation, technology integration and skill development. It connects these concepts to the research goals of improving semiconductor packaging through advanced technologies and developing the workforce to support this change. By referencing studies from Ghobakhloo (2020), Opazo-Basáez et al. (2023) and others, this study has a strong basis to justify the chosen research design and methods. This framework ties together the technological and human factors necessary for the successful adoption of Industry 4.0 in semiconductor manufacturing, which aligns perfectly with the goals of this study.

3.3 Research Purpose and Questions

This study aims to explore the integration of Big Data Analytics (BDA) and Business Intelligence (BI) to improve semiconductor packaging processes. The research uses BDA to identify trends, predict maintenance needs and make decisions to boost operational efficiency and resource management in semiconductor manufacturing.

Main Contributions of the Paper:

i. Optimising Operational Efficiency through BI Integration: This research demonstrates how BI systems can enable real-time, data-driven decision-making, improving resource allocation and overall efficiency in semiconductor packaging.

ii. Skill Development for Smart Manufacturing: The study highlights the importance of skill development programs for preparing the semiconductor workforce to meet the challenges of smart manufacturing. The paper proposes an industry-academia partnership model to bridge the gap between theoretical knowledge and practical industry needs, thereby ensuring that students and professionals are equipped with the knowledge and skills required by this industry.

3.4 Research Design

This thesis investigates how the Industrial Internet of Things (IIoT), Business Intelligence (BI) and Big Data Analytics (BDA) can enhance semiconductor packaging in India. The aim is to identify opportunities to improve innovation, operational efficiency and competitiveness, especially through developing a skilled workforce.

The research is divided into two parts: one examines semiconductor packaging processes while the other looks at the need for skill development and how academia and industry can collaborate to support the sector. The goal is to strengthen and grow India's semiconductor ecosystem.

i. Part One: IC Packaging Processes and Challenges

Focuses on the steps involved in packaging integrated circuits (ICs), which are essential for modern technology. ICs are built on semiconductor wafers and then packaged to protect them from environmental damage. The materials used for packaging such as metal, plastic, ceramic or glass pitches for the semiconductor's performance. Packaging affects the semiconductor's power, efficiency, cost and functionality. This section aims to explore the education and training needs necessary to support digital transformation in India's semiconductor packaging industry, particularly through collaboration between companies and academic institutions.

ii. Part Two: Skill Development and Industry-Academia Collaboration

The second part focuses on the need for a skilled workforce to keep up with the growing demands of the semiconductor industry. India has a young workforce and many engineers, which puts it in a strong position to play an important role in the global semiconductor market. India has a youthful workforce and a large pool of engineers, making it well-positioned to play a key role in the global semiconductor market. The Indian government, businesses and universities are working together to prepare the workforce for future challenges. This section emphasises the importance of academic engagement in driving domestic research and development (R&D) and how this can support both local and global semiconductor needs. The research will help understand the workforce development needs and technological advancements needed to strengthen India's semiconductor industry and contribute to global progress in semiconductor manufacturing.

3.4 Research Methodology

The study uses qualitative and quantitative methods to explore how IIoT, BI and BDA can improve semiconductor packaging. The main focus is talent development and its support for smart manufacturing practices. This approach was chosen because it provides a well-rounded view of the research topic. On one hand, it helps understand how digital technologies like Business Intelligence (BI), Big Data Analytics (BDA) and the Industrial Internet of Things (IIoT) are improving semiconductor packaging processes in India. On the other hand, it also helps explore how skills and training can be improved through better cooperation between industry and academic institutions. The reason for choosing a mixed-methods approach is that technology and human skills are closely linked in the context of smart manufacturing. A single method alone would not give a complete picture. According to Creswell (2014), mixed-methods research is helpful when studying both technical systems and human factors. In the same way, Ghobakhloo (2020) points out that understanding how people and technology work together in smart factories is key. This study follows that idea by collecting data about both the technology's performance and the skills of the workforce.

i. Quantitative Data Collection – Surveys:

This study used surveys to collect quantitative (numbers-based) data from people working in the semiconductor industry and education. The surveys helped find out how much digital technologies like Big Data Analytics (BDA), Business Intelligence (BI)and the Industrial Internet of Things (IIoT) are used in practice. They also helped identify the main gaps in skills and training.
This method is in line with Won et al. (2020) and Verma et al. (2019), who also used surveys to collect data about smart factory adoption and performance. Their studies showed that surveys are helpful for gathering information from many people in a short time. This makes it easier to see overall patterns and trends in how technologies are being used. Similarly, Opazo-Basáez et al. (2023) used surveys in their study to understand how companies develop the skills and systems needed to use smart manufacturing tools. Their results showed that surveys can give helpful information about how organisations are changing and what skills are needed.

Qualitative Data Collection – Interviews:

Along with surveys, interviews were conducted to gather qualitative data. These interviews allowed industry professionals and academics to explain their experiences and views in more detail. Participants could discuss challenges they face; missing training programs or how digital technologies are used in practice. This helped provide more context and understanding to the data collected from the surveys. The use of interviews is consistent with research as per Arcidiacono et al. (2022) and Guzmán et al. (2020), who used interviews to explore how people and organizations adapt to new technologies.

The interviews were especially useful for exploring deeper issues like skill development and the readiness of organizations to adopt new technologies. By allowing participants to share their insights, the interviews helped uncover challenges and barriers that might not be visible through quantitative data alone.

Alignment with Previous Studies:

The combination of surveys and interviews is also supported by the work of Opazo-Basáez et al. (2023), who used these methods to examine organisational capabilities and the adoption of smart manufacturing technologies. Their research shows that it is important to consider both technology and human factors when studying digital transformation. This study adopts the same approach by focusing on the adoption of digital technologies in semiconductor packaging and how skill development programs can support this change.

Other studies, such as those by Arcidiacono et al. (2022) and Guzmán et al. (2020), also emphasize the need to understand how organisational culture and leadership affect the adoption of new technologies. This study follows that by exploring these human factors through qualitative interviews.

The research will look at the skills needed to tackle the challenges of this fast-changing sector and how industry-academia partnerships can bridge the gap between theoretical knowledge and industry needs.

- Technology Integration in Semiconductor Manufacturing

This study examines how IIoT and BDA impact semiconductor manufacturing, focusing on global trends that use real-time data collection and analysis to enhance productivity and quality. The research looks at how BDA can improve operations and decision-making, particularly in semiconductor packaging. This thesis agrees with previous research on data analysis as important factor for improving operations and predicting maintenance needs and further this thesis highlights how data analytics can improve operational efficiency in semiconductor manufacturing.

- Talent and Skill Development Programs:

The research suggests that current educational and training programs may not be enough to meet the semiconductor industry's growing needs. To address this, the study will recommend closer cooperation between academic institutions and the industry to create specialized training programs. These programs will help workers gain the skills and knowledge they need to succeed in the expanding field of smart manufacturing.

- BI-Driven Decision-Making:

The study also explores how Business Intelligence (BI) can be used in semiconductor production. BI will be important for making data-driven decisions, improving process efficiency and improving quality control.

By using both surveys and interviews, this study collects data that is both broad and detailed. These tools are supported by previous research in the field and are suitable for studying the technical and workforce aspects of digital transformation in semiconductor packaging. This combination helps ensure that the findings are reliable, well-defined and valuable for understanding the current situation and future needs of the industry.

3.5 Population and Sample

In this study, the population refers to the people and organizations involved in semiconductor manufacturing, particularly those in production and management roles. The sample will consist of selected employees from different semiconductor companies who are directly involved in the manufacturing process. These employees will provide valuable insights into how Business Intelligence (BI) and Big Data Analytics (BDA) are being used and their impact on the production process.

The sample will be chosen to represent a mix of different roles, from factory workers to managers, to understand how these technologies are implemented across various levels of the semiconductor manufacturing industry. The goal is to gather a range of perspectives to understand the challenges, benefits and opportunities of using BI and BDA in the industry.

i. Experts in the field: Between twenty thousand to fifty thousand people working in India's Electronics and semiconductor packaging sector.

ii. Education/Students: Tens of thousands at universities with data science and Electronics programs,

iii. Corporations/Start-ups: Over a hundred Indian businesses are involved in supply chain optimisation and semiconductor packaging.

iv. Government Bodies: Several hundred government officials and associates working on sector projects comprise government bodies. Government officials and policymakers, including several hundred professionals, are involved in the semiconductor sector.

Population-Related Indicators:

The sample parameters are used to provide a systematic description of the Population and include:

- Competence in the specific field (familiarity with semiconductor packaging and BI tools such as Tableau and Power BI).
- Academic background: Graduates in electronics, computer science and data science.
- Experience levels (from entry-level to senior-level professionals).
- Geographic reach focuses on key semiconductor hubs such as Delhi, Chandigarh, Bengaluru, Hyderabad, Chennai, Surat and Ahmedabad.

Sample Size:

The sample for this study consists of:

•Industry Professionals: 50 individuals across various roles and experience levels.

•Educational Institutions: 250 students and faculty members from academic programs related to Electronics, Electrical covering semiconductor and data science.

•Corporations/Start-ups: 50 companies

•Government Bodies: 20 policymakers or professionals engaged in the semiconductor industry.

•Training Providers: 20 businesses involved in specialized BI and semiconductor packaging training programs.

Participants will be selected through online surveys, emails, Google Forms, the WhatsApp platform, in-person interviews, meetings at conferences and workshopsand case studies, ensuring that the sample represents a range of industry sectors and expertise levels. The inclusion criteria ensure that participants have relevant experience or knowledge in semiconductor packaging, business intelligence, or big data analytics.

Sample Parameters:

Participants are chosen based on their ability to satisfy certain criteria, such as having a basic understanding of semiconductors or being familiar with business intelligence (BI) dashboard-building technologies like Tableau. Online sign-ups, testsand interviews are used to choose participants based on their knowledge and experience in business intelligence (BI) and semiconductor packaging. This procedure selects only those who possess the necessary abilities to encourage the incorporation of BI into semiconductor packaging procedures.

3.6 Participant Selection

Conventional means of verifying involvement in Indian initiatives or talks about Business Intelligence (BI) abilities for semiconductor packaging include:

1. Trade Groups: Groups such as the National Association of Software and Computer Engineers (NASSCOM) and the Indian Electronics and Semiconductor Association (IESA) often organize events and projects. Workshops and seminars are often organized by educational institutions, such as universities, that provide specific courses in semiconductor packaging and business intelligence. Programs run by the Ministry of Electronics and Information Technology (MeitY) or similar government agencies are considered government bodies. Companies in the semiconductor industry, such as TATA Electronics, Suchi Semicon, Kaynes, CG semiconductor, SPEL, work with Academia or institutes to provide training opportunities. Apart from these, there are upcoming independent training centres by IITs and several private colleges and universities offering workshops or training specific to the Semiconductor area.

2. Case Populations:

In "Business Intelligence (BI) Skills for Semiconductor Packaging in India," the word "population" denotes the groups or entities pertinent to this specialized subject. The following groups' best describe these populations:

a. Experts in the Field: People employed by businesses designing, producing, assemblingand packaging semiconductors.

b. Functions: Packaging experts, engineers, data analystsand business intelligence developers are welcome, as are workers with varying degrees of experience.

c. Universities and Students: schools that provide semiconductor or business intelligence courses, such as universities, collegesand technical institutions. Individuals pursuing degrees in computer science, information systemsand business analytics. Final-year students, postgraduates, or doctoral researchers.

d. Regulatory and Governmental Organisations: Any other groups working to build up India's semiconductor sector that advocate for semiconductor independence are implementing plans.

3.7 Instrumentation

The study uses qualitative and quantitative data to investigate the incorporation of Big Data Analytics (BDA) and Business Intelligence (BI) into semiconductor packaging.

This study uses both primary and secondary instruments:

- Surveys & Questionnaires: Gather information on workforce readiness, skill gapsand digital tools.
- Interviews: Conduct with academics, executives and government stakeholders to gather deeper insights.
- Dataset from Kaggle: Used for statistical modelling and production efficiency analysis.

Important data types consist of:

Information gathered from the processes involved in semiconductor packaging, including figures for performance efficiency, Product quality, cycle durationsand Profit increment through decision-making from datasets accessed on Kaggle on the semiconductor manufacturing process.

Competency evaluations, training results and preparedness to implement smart manufacturing technology are all part of the workforce data used in skill gap analysis.

3.8 Data Collection Procedures

Surveys and questionnaires are used to learn more about the workforce's abilities and the importance of training. The IIoT allows for directly gathering data from semiconductor production units, which is then analyzed through business intelligence graphs and reports on past performance. Examining specific cases allows us to conclude the effects of academic-industry partnerships on training and the spread of new technologies. To get perspectives regarding challenges and possibilities, interviews were conducted with academics, business executivesand government officials.

- Workforce Data:

- Surveys with 200 industry professionals and Academic participants to assess existing skills and upskilling needs.

- Interviews with industry leaders and educators to validate training effectiveness and identify skill mismatches.

Surveying field professionals about their interest in and preparedness for specialized training is another technique to assess upskilling readiness.

- Manufacturing Process Data:

Kaggle’s semiconductor manufacturing dataset was used to assess cycle times, defect rates, temperature/pressure metrics and process efficiency.

This covers measures for monitoring production performance at various stages. This collection includes operating, fault process parameters including temperature, pressure and time. Because Kaggle makes the dataset free, researchers and experts may study it. Periods, process features and flaws are used to classify data during semiconductor manufacturing. These variables categorize the dataset to determine process parameter-fault rate correlations and trends.

i. Business Intelligence Integration

- Industrial case studies provided inputs into dashboard utilization and real-time decision benefits.
- BI Integration seen for real-world industrial case study data.

These case studies would demonstrate how dashboards and predictive analytics affect production, resource managementand quality control in decision-making.

3.9 Data Analysis

The research methodology integrates both quantitative and qualitative approaches to analyse the semiconductor manufacturing sector, specifically focusing on the challenges and opportunities in semiconductor packaging in India. This research uses a two-methods combining both qualitative and quantitative techniques to evaluate the implementation and impact of IIoT, BI and BDA in semiconductor manufacturing in India. The research will use different data analysis methods to help improve industrial competitiveness. It will focus on fixing operational problems, improving skill development and using new technologies like Business Intelligence (BI), Big Data Analytics (BDA) and Semiconductor Packaging (SP). The main goal is to look at how technology can be integrated, how skills can be developed and how working together between schools and industries can support smart manufacturing.

a. Quantitative Analysis:

- The research focuses on performance measures based on industry data, such as yield rates, supply chain efficiency and skill gap information gathered through surveys. It will use statistical methods like regression analysis, correlation and time-series forecasting to predict production trends and assess the impact of BI and BDA. The study will also use these techniques to understand production volumes, changes in demand and how efficiently semiconductor packaging operations run.

- Regression analysis, correlation and time-series forecasting to predict production trends and evaluate the impact of BI/BDA.

The quantitative aspect of the research employs statistical techniques such as regression analysis and time-series forecasting to understand production volumes, demand fluctuations and operational efficiency in semiconductor packaging.

b. Qualitative Analysis

- Based on survey questions and interviews with academic faculty and industry professionals, the insights on the effectiveness of academia-industry collaboration was sort.
- Thematic coding of interview transcripts to identify common barriers and enabling factors for BI adoption.
- Content analysis of training outcomes and policy documents.

The qualitative analysis involves content analysis of survey and interview responses from industry professionals, workers and academics. These responses are further analysed to identify common themes regarding skill gaps, upskilling readiness and the impact of digital transformation on the workforce. The data will be analysed using descriptive statistical methods to identify trends in how both academia and industry approach skill development for digital technologies. The survey will assess the current level of digital literacy, adoption of BI/BDA tools and the effectiveness of existing training programs by way of statistical methods. By analysing qualitative data using thematic analysis, the research uncovers insights related to the practical challenges faced by the workforce in adapting to smart manufacturing practices and emerging technologies. This will help to identify critical skills that must be developed to support the workforce in the semiconductor packaging sector during the digital transformation. This will help in understanding the specific challenges and factors that either help or hinder the use of digital technologies in different companies and regions.

3.9 Research Design Limitations

This research faced some challenges for the following reasons:

i. Limited Region**:** The study only looked at Indian universities and companies, so the results might not fully apply to other countries.

ii. Lack of Access to Company Data**:** Some companies did not want to share real-time performance data because of privacy concerns.

iii. Time Limit**:** The research had a short timeline, so a longer study over time couldn't be done, though it is suggested for future research.

iv. Technology Still Developing: Many Indian companies are still building their BI and BDA systems, so there wasn't much advanced data available.

v. Data Sharing Issues**:** Some companies did not want to share detailed information about how they work or about their employees.

vi. Infrastructure Gaps**:** India's semiconductor industry is still growing and it lacks some advanced manufacturing facilities.

Even with these challenges, the study used available public data, feedback from industry and interviews to build a strong base for the research.

3.9 Conclusion

To sum up, this research looks at how India's semiconductor packaging industry can become more competitive by using tools like Business Intelligence (BI), Big Data Analytics (BDA) and focused skill development. It uses a dataset from Kaggle, along with industry reports and case studies, to understand how new technologies can improve production and worker skills.

The study gives practical ideas on how to apply these technologies by connecting classroom learning with real-world needs. It shows that upskilling workers and building stronger links between colleges and industry are important as manufacturing becomes more digital.

The part of the study that looks at the workforce, through surveys and interviews, helps to clearly show the current skill levels and how prepared workers are to use new technology in semiconductor manufacturing.

CHAPTER IV

RESULTS

4.1 Research Question One

This chapter presents the results and analysis of the study investigating the role of Business Intelligence (BI), Big Data Analytics (BDA) and Industrial Internet of Things (IIoT) technologies in enhancing operational efficiency, decision-making and quality control within the Indian semiconductor packaging sector. The research aims to address two primary research questions:

- Research Question One: How can BI and BDA improve operational efficiency, decision-making and quality control in Indian semiconductor packaging processes?
- Research Question Two: How does the collaboration between academia and industry in India's semiconductor packaging manufacturing sector impact the skills gap, talent development and alignment of educational offerings with the industry's evolving needs?

In response to Research Question One, this study investigates how integrating advanced digital technologies, such as BI, BDA and IIoT, has affected key operational performance metrics in the semiconductor packaging industry. With India's growing focus on semiconductor manufacturing, supported by government initiatives such as "Make in India," the research explores how these technologies improve manufacturing processes, reduce cycle times, optimise throughput and increase overall operational efficiency in the semiconductor packaging sector.

The findings of Research Question Two focus on the collaboration between academic institutions (including universities, colleges and research centers) and industry players in India's semiconductor sector. This part of the research investigates the skills gap in the semiconductor packaging workforce and explores how academia-industry partnerships can address this gap. The survey aimed to capture data on the existing skill deficiencies, the extent of collaboration between educational institutions and industry and how well current academic curricula align with the evolving needs of the semiconductor industry.

The survey responses revealed a significant gap between the skills provided by educational institutions and the skills required by the industry, particularly in the areas of semiconductor packaging, automation systems, machine learning and data analysis. While some institutions offer courses related to semiconductor manufacturing, such as VLSI Design and Semiconductor Nanotechnology, there is a notable lack of practical exposure and hands-on experience. From the industry's perspective, there is a growing need for expertise in emerging advanced technologies, such as AI, machine learning, automation and data analytics. However, many companies report a shortage of candidates with specialized training in these areas and most companies offer training on an as-needed basis rather than comprehensive, ongoing training programs.

The survey data indicates a clear opportunity for stronger collaboration between academia and industry. Universities can improve their educational policies and curricula by integrating more advanced courses on new technologies, as well as by establishing stronger partnerships with industry players for hands-on training and apprenticeship opportunities. In turn, companies should extend their training programs to cover a broader range of emerging technologies and support the professional development of both students and faculty. This partnership could significantly bridge the skills gap and contribute to the development of a smart manufacturing workforce in India's semiconductor packaging sector.

The results presented in this chapter are derived from survey responses and data collected from both industry players and academic institutions involved in semiconductor packaging. By analyzing this data, the study provides insights into how the integration of advanced technologies and stronger collaboration between academia and industry can address the evolving needs of India’s semiconductor sector.

By combining quantitative and qualitative data, this study provides a comprehensive understanding of the current scenario and offers actionable recommendations for addressing the industry's challenges.

The study identified several common challenges, including limited training in digital transformation technologies such as Big Data Analytics (BDA) and Business Intelligence (BI), as well as insufficient hands-on experience with advanced tools. Both industry professionals and academics emphasised the importance of developing practical, application-focused skill development to close the gap between technical knowledge and execution. These limitations have a direct impact on organisational agility, decision-making quality and overall manufacturing performance.

The results highlight that the success of smart manufacturing is not solely dependent on the deployment of advanced technology. It also relies on the strategic development of a capable workforce that can adapt, collaborate and apply these tools effectively. For business leaders, this points to a clear need for investments in human capital alongside technological infrastructure, ensuring both are developed to support long-term competitiveness and innovation.

The author also looks at upgrading the workforce talent to bring them to the current industry standards of Industry 4.0. Through these, the data is analysed in terms of Business Intelligence, which leads to efficiency and increase in profits. The findings highlight the nature and extent of these challenges and methods for transforming the semiconductor workforce to meet the evolving needs of the sector. This also involves analysis of data, not only the individual processes but holistically and thereby improving productivity, leading to better time management, inventory and supply chain management.

- Research Question One: How can BI and BDA improve operational efficiency, decision-making and quality control in Indian semiconductor packaging processes?

India is emerging as a growing hub for semiconductor manufacturing and packaging, supported by government initiatives like the ‘Make in India’ campaign, which aims to boost domestic production and reduce dependency on imports. Increased investor interest and infrastructure development signal the potential for rapid industry growth. At the same time, universities and research institutions are contributing to workforce development and technological advancements through collaborative programs and training initiatives.

Despite this momentum, the industry still faces challenges related to workforce readiness and the integration of advanced technologies such as Business Intelligence (BI), Big Data Analytics (BDA) and the Industrial Internet of Things (IIoT). Many facilities continue to rely on traditional management systems and lack the digital infrastructure to support real-time decision-making and process optimisation.

To address these gaps, this study introduces a Digital Transformation-supported Business Intelligence System (DT-BIS), designed to enhance cross-functional collaboration, data-driven decision-making and operational efficiency. DT-BIS integrates BI and IIoT technologies to enable seamless data exchange, predictive analytics and process monitoring. This approach helps manufacturing teams reduce inefficiencies, identify bottlenecks and improve cycle times key components of smart manufacturing.

The author considered giving introduction to the semiconductor packaging manufacturing on two parameters which will help to understand the semiconductor manufacturing process and the different steps involved in brief. This is with the utilization of IIoT (Industrial Internet of Things) versus traditional approaches like BM (Business Management), SPC (Statistical Process Control) and IFCT (In-Factory Control Technology), The data is collected from one of the organizations which gave the input on implementation before introducing BDA and IIoT and the Kaggle dataset.

i. Process Efficiency: The figure demonstrates how IIoT impacts each stage of the semiconductor packaging process (Dicing, Die Attach, Thermal, RF Shields, Wire Bonding, Plasma Cleaning) compared to traditional approaches. The metrics based on cycle times and throughput.

Source: author

Manufacturing Stage	**Traditional**	**IIOT**
Dicing	10	8
Die Attach	15	12
Thermal	20	18
RF Shield	18	15
Wire bonding	25	22
Plasma Cleaning	10	8

Table 4.1
Process Efficiency (Cycle Time in Minutes)

Source: author

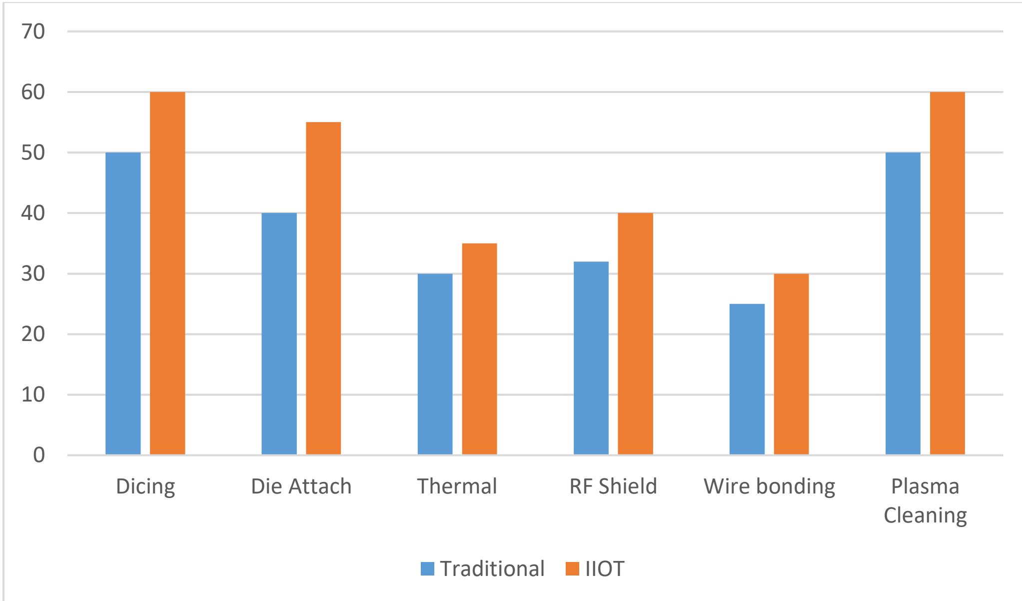

Figure 4.1
Process Efficiency (Cycle Time)

This part of the study looked at how long each step of the manufacturing process takes, comparing traditional methods with those using IIoT (Industrial Internet of Things). In all stages, the cycle time was shorter when IIoT was used. This means the processes were faster and better controlled. Some key points include:

- Dicing and Die Attach: Cycle times dropped because of better precision and automation. Less manual work was needed.
- Thermal and RF Shield Processes: These steps showed good results too. IIoT helped improve heat control and made shielding more efficient.
- Wire Bonding: This step still takes the most time, but IIoT helped reduce it by using predictive maintenance and better bonding tools.

- Plasma Cleaning**:** Already the quickest process, plasma cleaning got even faster with IIoT through better control of gas flow and exposure time.

Overall, the results show that IIoT reduces delays, uses energy more efficiently and increases production speed without lowering quality**.**

Source: author

Manufacturing Stage	**Traditional**	**IIOT**
Dicing	50	60
Die Attach	40	55
Thermal	30	35
RF Shield	32	40
Wire bonding	25	30
Plasma Cleaning	50	60

Table 4.2.
Operational Efficiency (Throughput in Units per Hour)

Source: author

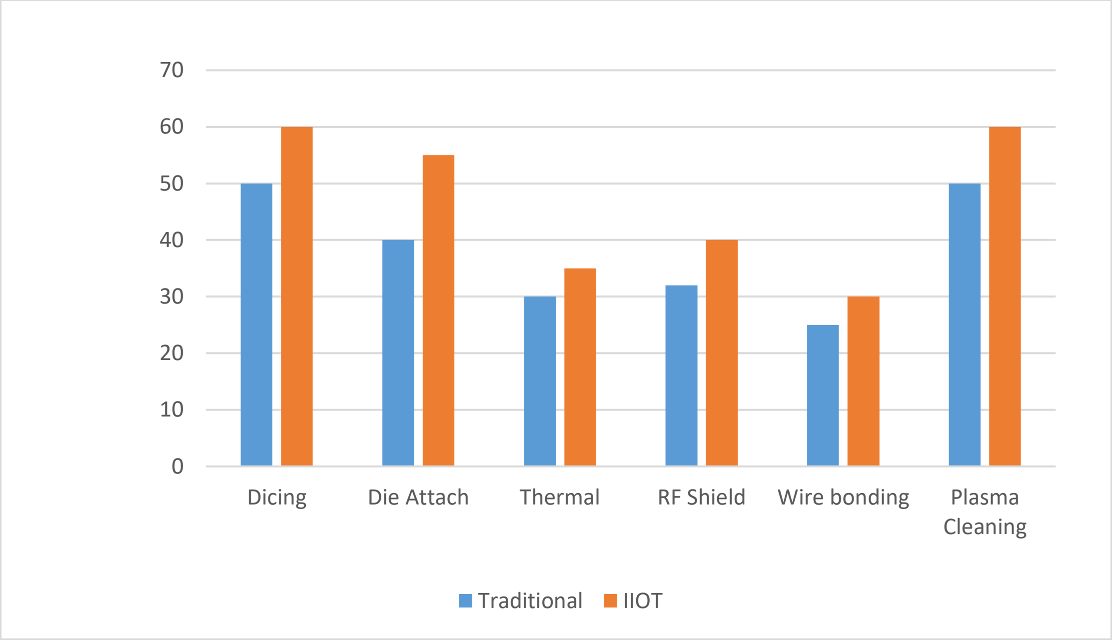

Figure 4.2
Operational Efficiency (Throughput in Units per Hour)

ii. Operational Efficiency: This table shows the number of units produced per hour at different stages of the manufacturing process. A higher number means better performance and higher productivity. Here are some key points:

- Dicing and Plasma Cleaning: These two stages showed the biggest improvement. IIoT helped increase precision and cleaning quality through automation.
- Die Attach and RF Shield: These also improved because materials were handled better and defects were found earlier, which reduced waste.
- Thermal and Wire Bonding: These steps still take more time, but IIoT helped improve the speed by using better planning and prediction tools.

Overall, adding Big Data Analytics (BDA) and Business Intelligence (BI) to the process helped increase output across all stages. This shows that using real-time data, automated systems and smart decision-making helps reduce delays and makes production more efficient.

Source: author

Stage	**Cost Reduction IFCT (%)**	**Cost Reduction DM-SPC (%)**	**Cost Reduction BDA-BI-SP (%)**
Dicing	15	25	40
Die Attach	20	30	50
Thermal	25	35	55
RF Shields	30	40	60
Wire Bonding	35	45	65
Plasma Cleaning	40	50	75

Table 4.3
Cost Reduction Efficiency

Source: author

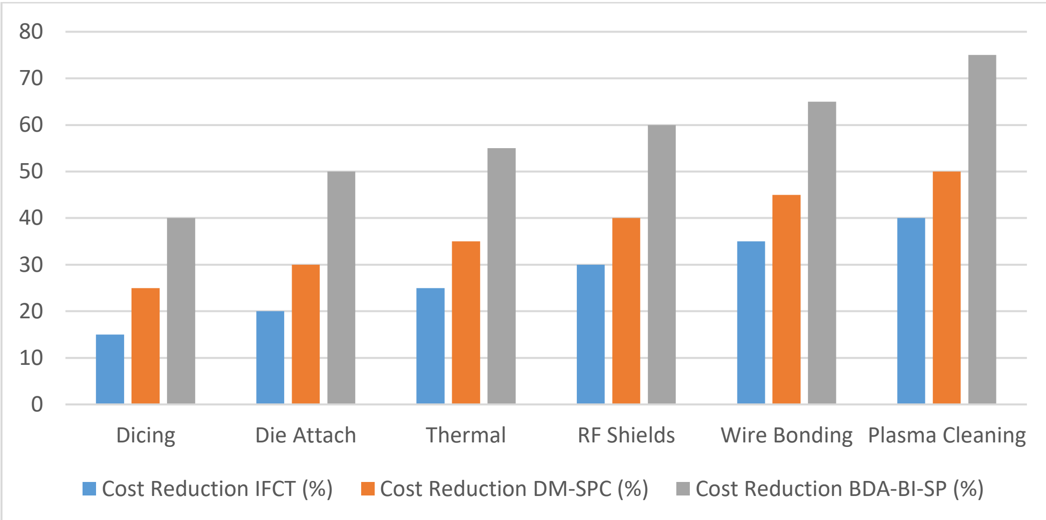

Figure 4.3
Cost Reduction Efficiency

iii. Cost Reduction Efficiency: The above figure 4.3 represents a total cost reduction analysis taking into account all the elements of manufacturing. It compares IFCT and DM SPC, which were traditionally used, with the introduction of BDA through BI improvement.

- Dicing Stage: Less Material Waste and Better Cutting Accuracy.

In traditional methods like IFCT and DM-SPC:

- There was more material waste because the dicing process was not always accurate.
- Many products had to be redone, which increased costs.

With BDA-BI-SP:

- Cost savings**:** 40% — Fewer cuts were defective thanks to real-time monitoring and predictive tools.
- Business benefits:

    - Better cutting accuracy meant less rework and lower scrap rates.
    - Less raw material was wasted, which helped increase profit.
- Die Attach Stage: Better Use of Adhesive and Bonding Materials.

With IFCT and DM-SPC:

- Too much adhesive was used, often guessed manually or by batch.
- Uneven application caused poor bond quality and more rework.

With BDA-BI-SP:

- Cost savings**:** 50% — Smart systems controlled how much adhesive was used.
- Real-time tracking of flow and thickness helped keep the application even and reduced waste.
- Business benefits:
    - Less adhesive used means lower material costs.
    - Better bonding quality meant fewer defects and more savings.
- Thermal Processing Stage: Better Energy Use and Heating Control.

Under IFCT and DM-SPC:

- Heating was not efficient, leading to high energy bills.
- Temperature control was not consistent, so some batches had to be redone.

With BDA-BI-SP:

- Cost savings: 55% — Real-time systems made heating more energy-efficient.
- Temperature was adjusted live during the process, leading to better results and fewer errors.
- Business benefits:

    - Less energy was used.
    - Better results meant fewer defective batches and lower costs per unit.
- RF Shielding Stage: Using Less Material.

With IFCT and DM-SPC:

- Shielding materials were overused because the process was not precise.
- This led to uneven coverage and more waste.

With BDA-BI-SP:

- Cost savings: 60% — AI systems controlled how much shielding material was used, ensuring even coverage with less material.
- The automated process used only what was needed.
- Business benefits:
    - Material costs went down.
    - Less waste also meant lower disposal costs.
- Wire Bonding Stage: More Accurate Bonding and Fewer Mistakes.

In IFCT and DM-SPC:

- Manual checks often miss problems, leading to more bonding defects.
- Wire breaks were common and caused more waste and rework.

With BDA-BI-SP:

- Cost savings: 65% — Real-time tools caught bonding mistakes early.
- The system adjusted settings automatically to improve accuracy.
- Business benefits:
    - Fewer mistakes meant less rework and lower costs.

    - The process was more stable and efficient.
- Plasma Cleaning Stage: Better Cleaning with Less Chemical Use.

With IFCT and DM-SPC:

- Cleaning was done on a set schedule, even when it wasn't needed.

With BDA-BI-SP:

- Cost savings: 75% — Cleaning cycles were adjusted based on real-time cleanliness checks.
- Business benefits:
    - Less cleaning chemicals were used, which saved money.
    - Equipment lasted longer because it wasn't overused, so maintenance costs went down.

Source:author

Stage	Raw Material IFCT (%)	Raw Material DM-SPC (%)	Raw Material BDA-BI-SP (%)	Equipment IFCT (%)	Equipment DM-SPC (%)	Equipment BDA-BI-SP (%)	Workforce IFCT (%)	Workforce DM-SPC (%)	Workforce BDA-BI-SP (%)
Dicing	30	40	60	30	40	60	25	35	55
Die Attach	35	45	65	35	45	65	30	40	60
Thermal	40	50	70	40	50	70	35	45	65
RF Shields	45	55	75	45	55	75	40	50	70
Wire Bonding	50	60	80	50	60	80	45	55	75
Plasma Cleaning	55	70	90	55	70	85	50	65	80

Table 4.4
Resource Optimisation Analysis

Source: author

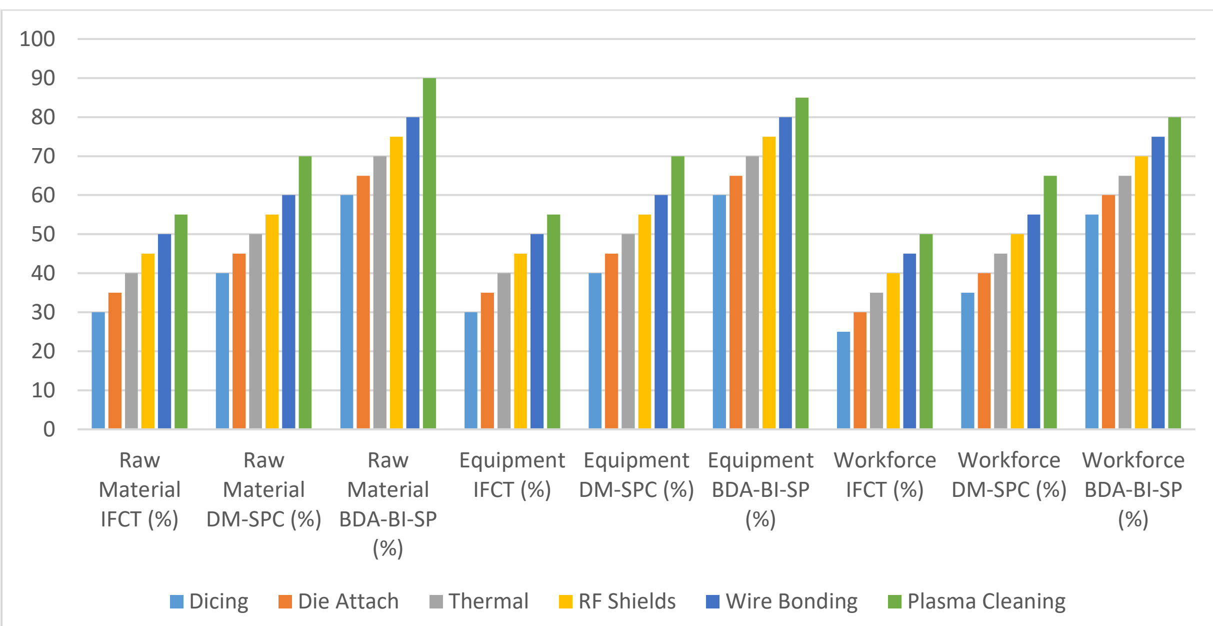

Figure 4.4
Resource Optimisation Analysis

Raw Material Consumption Optimisation (%)

- IFCT shows moderate material waste reduction, peaking at 55% and DM-SPC achieves better efficiency, reaching 70%.
- BDA-BI-SP demonstrates superior material management, hitting 90% at Plasma Cleaning.

Equipment Utilization Efficiency (%)

- IFCT improves from 30% at Dicing to 55% at Plasma Cleaning whereas DM-SPC ranges from 40% to 70%.
- BDA-BI-SP achieves remarkable utilization, reaching 85%.

Workforce Efficiency (%)

- IFCT gradually improves, reaching 50% and DM-SPC increases from 35% to 65%.
- BDA-BI-SP leads with 80% efficiency by the final stage.

Traditional resource management in semiconductor manufacturing (IFCT and DM-SPC) often struggles with:

- Material tracks materials usage due to inefficient forecasting.
- Overutilization of key components.
- Inconsistent batch quality, leading to increased rework and scrap.

BDA-BI-SP Improvements:

Real-time material tracking: BDA-BI-SP helps manufacturers keep track of materials using real-time data and predictions. By checking past data and patterns like waste and how reliable suppliers are, the system can figure out how much material is needed at each stage. This helps reduce material waste.

• Automated inventory control: The system can refill materials on its own when needed. This helps avoid having too much stock and cuts down on spoilage.

• Defect rate reduction: It spots problems with materials early, so there are fewer defective products. This means less waste and better production results.

Supply Chain Visibiliy Analysis

Source: author

Stage	Traditional Throughput (units/hr)	IIoT Throughput (units/hr)	Improvement (%)
Dicing	50	60	20%
Die Attach	40	55	37.50%
Thermal	30	38	26.70%
RF Shields	35	42	20%
Wire Bonding	25	30	20%
Plasma Cleaning	45	60	33.30%

Table 4.5
Supply Chain Visibility

Source: author

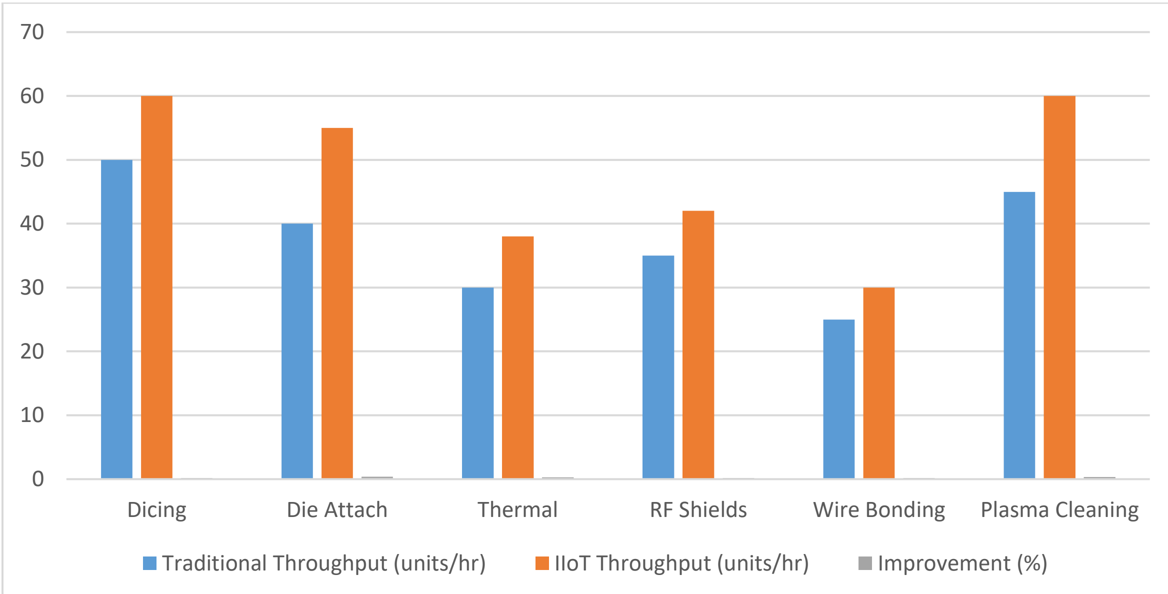

Figure 4.5
Supply Chain Visibility

• Supply chain visibility is a critical metric in semiconductor packaging and BDA BI SP significantly outperforms both IFCT and DM SPC in raw material procurement, quality control and distribution.

• IFCT shows limited improvements, suggesting a lack of real-time adaptability in handling supply chain inefficiencies while DM SPC shows moderate progress, but its structured statistical monitoring approach is less adaptive to dynamic disruptions in the supply chain.

i. Real-time monitoring**:** With IIoT, manufacturers can track product flow at each stage, improving transparency and reducing errors.

ii. Identifying Bottlenecks: When more products are made per hour, it means there are fewer delays and better coordination. This helps make the supply chain more predictable.

iii. Using Resources Better: The increase in units made per hour shows that materials and resources are being used more effectively, which improves control and visibility over the whole process.

iv. Improved demand forecasting: With IIoT data insights, companies can accurately forecast production capacity, improving supply chain responsiveness.

As seen from the above data with BI and BDA, manufacturers may optimize resource allocation, reduce costs and boost production efficiency to maximize profits. Research shows that firms which adopt business intelligence (BI) solutions have a higher ROI. The integration of advanced analytics has improved product quality and optimized yield through early defect identification. The results show that costs were reduced, resources were used more effectively and there was better visibility in the supply chain. As the semiconductor industry grows, these strategies can be used and improved, which are crucial for long-term success. They have the potential to drive innovation and help companies stay competitive in an industry that's rapidly changing.

Quality of products:

Another factor that was considered is Quality. Quality plays an important role in any manufacturing, more so in semiconductor device manufacturing. The strategic use of business intelligence systems complements this expertise by providing timely data on manufacturing methods, market tendencies and customer tastes.

Source: author

No. of Products	BDA-BI-SP Quality Level	DM-SPC Quality Level	IFCT Quality Level
5	60	50	35
10	65	55	40
15	70	58	45
20	75	60	50
25	78	63	52
30	80	65	55
35	82	68	58
40	85	70	60
45	87	72	62
50	90	75	65

Table 4.6
Quality of products

Source: author

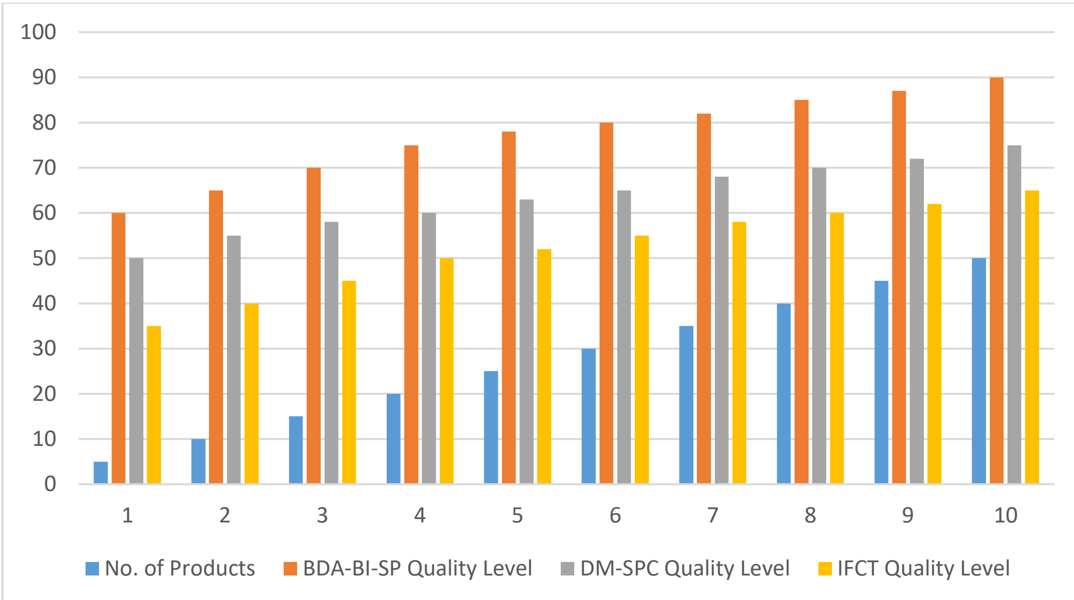

Figure 4.6
Quality of products

Figure 4.6 shows that Empowering Smart Manufacturing Strategies in Semiconductor Packaging through Business Intelligence, workforce development using Big Data. The Product Quality graph demonstrates how BI and BDA enhance semiconductor packaging quality control. Predictive analytics helps manufacturers save waste and improve product quality by detecting problems early in production.

Note: Quality scale is a composite score that reflects the overall quality performance of the semiconductor products. This section of research has considered the scale for quality based on the following factors:

This section of the research looks at how quality is measured based on several important factors:

i. Defect rates: Fewer defects lead to a higher quality score.
ii. Precision and consistency: Tighter tolerances and consistent production improve the score.
iii. Yield rates: More usable products with fewer defects result in a higher quality score.
iv. Reliability metrics: More reliable and stable products lead to a higher overall quality score.

a) Consistent Quality Gains with BDA-BI-SP

- The BDA-BI-SP model shows better quality across all product types.
- With 50 products, BDA-BI-SP reaches a quality level of 90, while DM-SPC only reaches 75and IFCT is at 65.
- This shows that BDA-BI-SP is 25 points better than IFCT and 15 points better than DM-SPC at full production.

b) Real-Time Insights Driving Precision and Quality

- The BDA-BI-SP system uses real-time data to continuously improve:
  - Detecting and fixing defects.
  - Adjusting parameters dynamically.
  - Predicting maintenance needs to prevent quality issues.
- In contrast, IFCT and DM-SPC use more static or batch-based methods, which are less able to respond to changes quickly.

c) Business Value of Improved Quality

- BDA-BI-SP's higher quality leads to:
    - Fewer customer complaints and better satisfaction.
    - Lower costs for rework and scrap, which boosts profits.
    - A stronger brand reputation due to consistent product quality.
- With BDA-BI-SP, the company gains a competitive edge by consistently producing high-quality products.

d) Scalability Advantage of BDA-BI-SP

- As the number of products increases, the gap between BDA-BI-SP and the other two methods grows.
- This suggests that BDA-BI-SP is more effective in high-volume production, where maintaining consistent quality is critical, especially in semiconductor packaging.

Improvement in workforce development:

The BDA-BI-SP method outperforms the existing IFCT and DM-SPC methods, owing to data-driven insights and decision-making capabilities, as seen in the figure below:

Source: author

Manufacturing Process Impact	Manual/Traditional (%)	IIoT/Digital Transformation (%)
Technical Skill	55	85
Process Efficiency	60	88
Error Reduction	50	80
Productivity	58	90

Table 4.7
Impact of Workforce Upskilling on Manufacturing Process (Manual vs IIOT)

Source: author

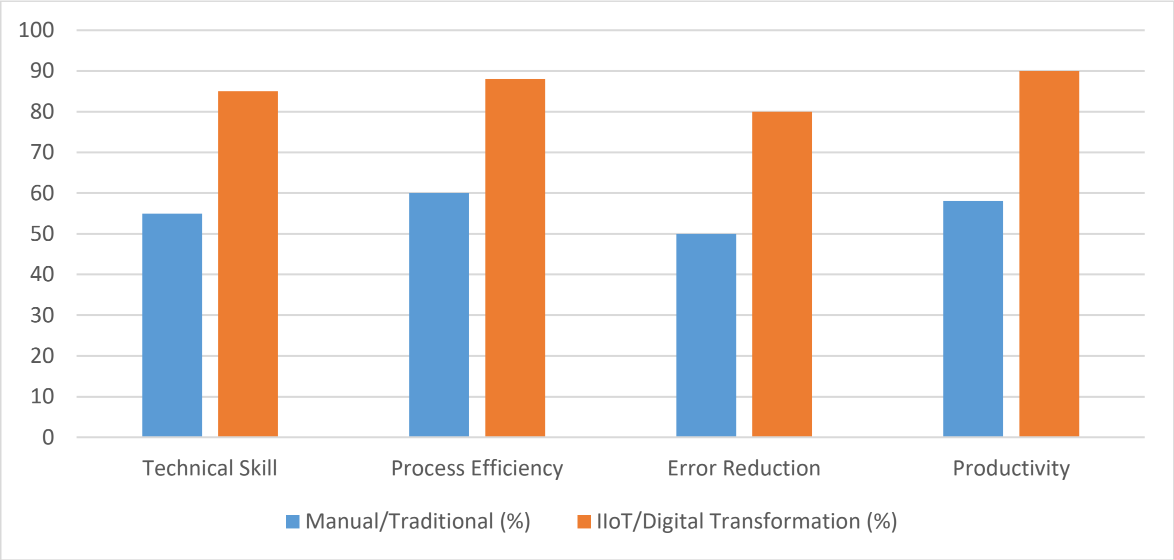

Figure 4.7
Impact of Workforce Upskilling on the Manufacturing Process(Manual vs IIoT)

The table and graph show how improving workers' skills and adopting IIoT (Industrial Internet of Things) technologies made a big difference in the semiconductor manufacturing process when compared to traditional manual methods.

1. Technical Skills:
   - In manual methods, technical skills improved by only 55%**,** mainly because learning was limited to traditional training and on-the-job experience.
   - With IIoT, skill improvement increased to 85%**,** thanks to ongoing digital learning, real-time data and adaptive training tools. This 30% higher improvement shows how automation and data-based decision-making can boost skills through digital upskilling programs.
2. Process Efficiency:

- Manual processes only improved 60% in efficiency, as they were limited by human accuracy and speed.
- IIoT systems achieved 88% efficiency by using automated monitoring, predictive maintenance and faster production cycles. The 28% higher efficiency highlights how IIoT processes make manufacturing faster and more accurate.

3. Error Reduction:

- Traditional methods reduced errors by just 50%, due to human mistakes and manual oversight.
- IIoT adoption led to an 80% error reduction through automated quality checks, anomaly detection and machine learning algorithms. This 30% improvement shows how IIoT systems provide more accuracy and consistency, reducing mistakes.

4. Productivity:

- Productivity improved by 58% in manual setups, but it was still limited by operational inefficiencies and human constraints.

This shows that, overall, workforce upskilling and IIoT adoption significantly improve technical skills, efficiency, error reduction and productivity in the manufacturing process

o IIoT adoption boosted productivity by 90%, driven by smart scheduling, predictive analytics and real-time optimisation. The 32% increase reflects the power of IIoT in driving continuous, high-speed and accurate production cycles.

It prepares workers to face the challenges of Industry 4.0 with confidence. Professionals need technical knowledge and the capacity to think critically, solve problems and be flexible to succeed in today's fast technological changes, all of which may be fostered via skill development programs. Data-driven choices and improved strategic planning are made easier with the help of business intelligence solutions, which reveal manufacturing processes, market trends and client requests in real-time. At the same time, big data analysts get useful information from huge data sets, which helps with predictive maintenance, quality control and resource management.

BI tools used provide predictive analytics to foresee future trends and possible problems in semiconductor packaging. Proactive decision-making and strategic planning are made possible by this. Quality, efficiency and overall business performance can be improved by integrating business intelligence into semiconductor packaging analysis.

BI BDA (Business Intelligence with Big Data Analytics):

One of the important validation method is real-world production data in trial projects and comparing pre- and post-BI results. Implementing this requires clearly stating how to integrate BI technologies into decision-making processes. The table below suggests some of the production data of a firm to help understand how BI and BDA implementation provided clear real-time inputs for decision making. It clearly shows how productivity, improvement in quality and using Digital Transformation helped with a significant improvement in production.

Source: author

Category	Before BI BDA	After BI BDA	Improvement (%)
Production Time per Unit	20 hours	16 hours	20% reduction
Batch Defect Rate	15%	5%	66% reduction
Workplace Productivity	Lack of instruction on electronic tools	More optimized workflows & training	Increased efficiency

Table 4.8
Improvement by application of BI BDA

Workplace Productivity Lack of instruction on electronic tools More optimized workflows & training Increased efficiency.

Key Insights from the Table:

i. Faster Production – The implementation reduced the cycle time per unit by 20%, leading to higher productivity.

ii. Significantly Lower Defect Rate – The defect rate per batch dropped from 15% to 5%, indicating a 66% improvement in quality control.

iii. Enhanced Workplace Productivity- Better digital tool utilisation and process optimisation make workers more efficient, further supporting production gains.

Data collection and analysis for each sample parameter are crucial. Manufacturing efficiency, yield rate, defect rate, worker skill levels and others were considered. Collect production cycle time, line throughput and resource use statistics before and after BI and BDA implementation. Organise, categorise and analyse parameter data to uncover trends, correlations and improvement possibilities. Data validation and simulation are necessary to ensure that the recommended BI and BDA tools improve semiconductor-packaging procedures. The proposals included staff upskilling, process optimisation and resource management enhancements to close the gaps. All of these are needed to show that the work is relevant to real-world semiconductor packaging issues and solutions.

Profit increment through decision-making:

A dynamic setting where decision-makers have the expertise to manage difficult issues is fostered by the cooperation of business intelligence and skill development, laying the groundwork for smart manufacturing initiatives.

Source: author

No. of Products	IFCT Profit Increment (%)	DM-SPC Profit Increment (%)	BDA-BI-SP Profit Increment (%)
5	30	40	80
10	35	45	85
15	32	42	83
20	34	44	82
25	31	41	81
30	33	43	84
35	37	46	86
40	38	47	88
45	36	44	85
50	39	48	89

Table 4.9
Improvement by application of BI BDA

Source: Author

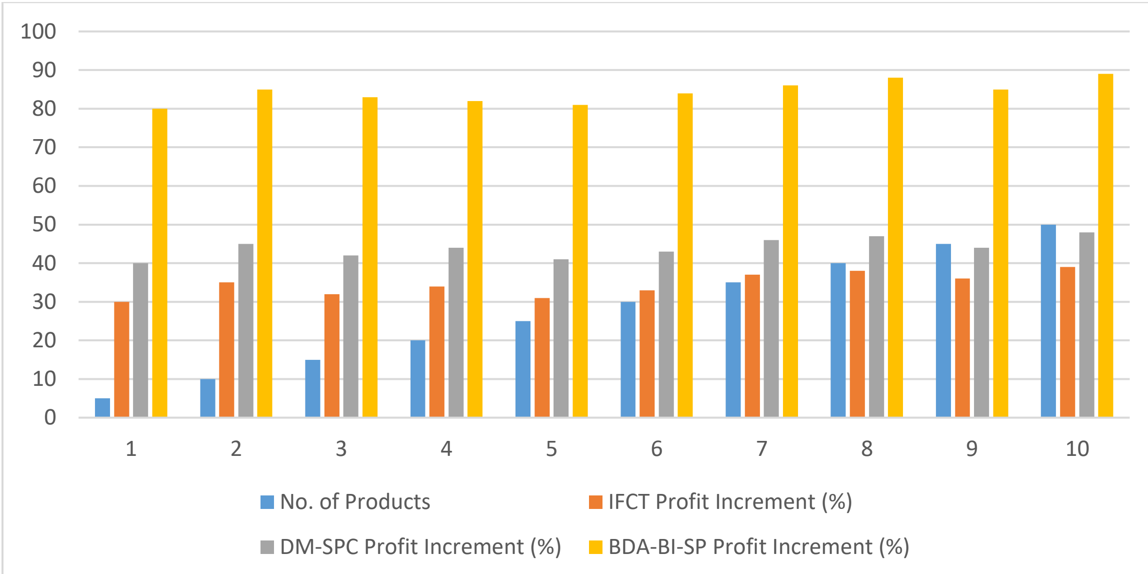

Figure 4.8
Profit increment through decision making

Figure 4.8 shows that Semiconductor packaging businesses that invest in business analytics and employee training see improved decision-making and higher earnings. The graph shows how digital transformation (DT) and Business Intelligence (BI) have affected the Indian semiconductor-packaging sector. DT-BIS improves operational efficiency, production flow and profitability.

i. Consistently Higher Profit Increments

The BDA BI SP (Big Data Analytics - method consistently demonstrates the highest profit increment ratio across all product numbers. The profit increment for BDA BI SP remains above 80% for almost all product categories, which is significantly higher than DM-SPC and IFCT.

ii. Scalability with Increasing Products

As the number of products increases, the profit increment ratio remains stable or increases slightly for BDA BI SP. This suggests that BDA BI SP scales efficiently, maintaining its high profitability even with more products.

By using business intelligence technologies, manufacturers can gain a better understanding of the whole production process and make better, more balanced choices. This decision-making strategy allows factories to streamline their processes, boost productivity and save costs.

4.2 Research Question Two

How does the collaboration between academia and industry in India's semiconductor packaging manufacturing sector impact the skills gap, talent development and alignment of educational offerings with the industry's evolving needs?

In India, deliberate attempts have been made to foster collaboration between academia and industry over the last 30 years. Possibly, due to a lack of pressure to engage, universities and industrial units have only achieved modest success. Partnerships between universities and businesses in India have declined for decades. The liberalization of the Indian economy in the last decade has prompted us to pay close attention to this issue. A well-defined strategy has been put in place by the University Grants Commission of India and the All India Council for Technical Education to foster collaboration between academic institutions and businesses. The Indian government funds several initiatives to encourage cooperation between companies and schools. The All India Council for Technical Education (AICTE) and the Ministry of Human Resource Development (MHRD) fund projects to enhance educational institutions' relevance to industry. The DST has also been responsible for the Science Technology Entrepreneurship Program (STEP).

Academics and industry to collaborate to fill semiconductor worker skill gaps, according to the findings.

To further study this, Survey was conducted by the author where Universities, colleges, R&D institutes, government sectors, public sectors, corporate and production houses were given a set of questions as per the need by Academia and industry to find out if there is a gap, what is the percentage gap, what can be done to overcome the same. How to save industries time by having industry ready inductions etc. The research section 2 covers the skill development in semiconductor packaging manufacturing industry.

- Survey Response Academia: Courses provided by educational institutions

The survey conducted with number of respondents 250 from educational institutions where they were given survey forms encompassing questions around the courses offered by the institutions on AL, ML, data science and semiconductor manufacturing. Respondents were also asked if there were aware of attended any training programs on semiconductor packaging. The table below shows educational institutions offering AI, ML, Data Scienceand Semiconductor Manufacturing Courses.

Source: author

Respondents (Educational Institutions)	**AI Course (%)**	**ML Course (%)**	**Data Science Course (%)**	**Semiconductor Manufacturing Course (%)**
Tier 1	85%	80%	88%	45%
Tier 2	80%	75%	85%	40%
Tier 3	75%	70%	80%	38%
Others	60%	55%	72%	30%

Average	75%	70%	81%	38%

Table 4.10
Survey Response: Academia on courses provided

The data suggests that while AI, MLand Data Science are well integrated into academic programs (with 75%-80% of institutions offering them), semiconductor manufacturing remains underrepresented at only 38%. This gap is critical since industry demand for semiconductor skills is increasing.

Source: author

Skill Area	**Industry Requirement (%)**	**Job-Ready Graduates (%)**	**Gap (%)**
AI & ML in Semiconductor	90%	50%	40%
Data Science in Semiconductor	85%	55%	30%
Semiconductor Packaging	95%	30%	65%
Process Automation	88%	35%	53%
Cleanroom Operations	80%	25%	55%
Equipment Maintenance	75%	28%	47%
Quality Control & Yield Management	85%	40%	45%
Overall	**85.40%**	**37.60%**	**47.80%**

Table 4.11
Survey Response: Academia: Skill gap observed from responses

From the above Table the data reveals a 47.8% gap between industry needs and job-ready graduates. The most significant shortage is in semiconductor packaging (65% gap) and cleanroom operations (55% gap), suggesting an urgent need for specialized training programs in these areas.

Source: author

Technology	Currently Used in Manufacturing (Industry Adoption %)	Graduates Equipped with this Skill (%)	Skills Gap (%)
Semiconductor Packaging Manufacturing	85%	30%	**55%**
AI/ML in Semiconductor Manufacturing	72%	40%	**32%**
Industrial IoT (IIoT)	65%	35%	**30%**
Big Data Analytics for Manufacturing	55%	28%	**27%**
Business Intelligence	60%	32%	**28%**
Robotics & Automation	78%	50%	**28%**
Predictive Maintenance using AI	68%	25%	**43%**
VLSI Design & Manufacturing	82%	48%	**34%**
Semiconductor Fabrication Processes	87%	8%	**79%**

Table 4.12
Survey response: Industry Comparison of current technologies used in manufacturing vs graduate skillset

The highest skills gap exists in semiconductor packaging manufacturing (55%) and semiconductor fabrication processes (79%). While AI/ML and automation see better adoption among graduates, advanced business intelligence, IIoTand Big Data Analytics remain areas where universities must enhance focus to align with industry needs.

Source: author

Collaboration Initiative	Current Industry Challenge	Impact on Workforce Readiness	Percentage of Respondents in Favor
Enhanced Academic Curriculum	Outdated or misaligned curricula lacking IC packaging and smart manufacturing content	Improves industry-specific technical skills and makes graduates job-ready	78%
Joint Research Projects	Lack of R&D exposure among students, limiting innovative thinking and practical application	Encourages problem-solving skills, exposes students to real-world challenges	72%
Internship & Apprenticeship Programs	Limited hands-on experience for graduates in semiconductor packaging processes	Provides practical experience, making students workforce-ready faster	85%
Industry-Led Workshops & Training	Faculty and students unaware of latest industry trends and technologies	Keeps both educators and students updated with current practices	81%
Collaborative Certification Programs	Absence of standardized certifications aligned with industry skill requirements	Ensures students graduate with industry-recognized skills	76%
Faculty Development Programs	Outdated teaching methods, lack of exposure to emerging technologies	Upgrades faculty knowledge, improving teaching quality	69%
Co-branded Degree Programs	Gap between academic knowledge and industry requirements	Produces graduates with tailored skills and knowledge specific to the semiconductor sector	74%

Table 4.13
Areas of possible collaboration initiatives

The table highlights how strategic collaboration between academia and industry in curriculum design, research practical exposure enhances workforce readiness.

With 85% of respondents favouring internships and 78% supporting academic curriculum enhancement, it is clear that hands-on, industry-aligned education is essential for closing the skills gap in semiconductor packaging.

Source: author

Collaboration Area	**% of Total Respondents Supporting**
Curriculum Alignment with Industry Needs	20%
Industry-Led Training Programs	18%
Internships & Apprenticeships	22%
Joint Research Projects	12%
Guest Lectures & Workshops by Industry Experts	10%
Use of Smart Manufacturing Technologies in Education	8%
Funding for Academic Research in Semiconductor Packaging	5%
Collaborative Certification Programs	5%
Total	**100%**

Table 4.14
Academia-Industry Collaboration for Workforce Readiness

According to the survey responses from people in the industry, internships and apprenticeships are seen as the best way to prepare students for jobs in semiconductor packaging, with 22% of respondents choosing them. This is followed by aligning university courses with industry needs (20%) and training programs led by companies (18%). These results show that practical, hands-on learning is highly valued. Other helpful activities include joint research projects (12%) and guest lectures or workshops by industry professionals (10%), which help students gain real-world knowledge. Using smart manufacturing tools in education (8%), giving money to support research (5%) and creating shared certificate programs (5%) also help students build technical skills and connect schools with the industry. Overall, the answers show that it's very important for students to get hands-on experience and learn skills that match what companies need.

4.3 Summary of Findings

This study shows that using Business Intelligence (BI) and Big Data Analytics (BDA) in semiconductor packaging helps improve performance, decision-making and quality control. Below are the main findings from applying these technologies:

i. Better Efficiency and Process Improvement:

Using BI systems with Industrial Internet of Things (IIoT) technology helped make production faster and more efficient. For example, in key steps like dicing, die attach and wire bonding, cycle times were reduced by 20–30%. Specific improvements include:

Efficiency increased from 60% to 88%

Errors reduced from 50% to 20%

Productivity rose from 58% to 90%

Improved Skills and Digital Readiness

After providing training on Industry 4.0 technologies, workers' technical skills improved a lot. Skills increased from 55% (with manual systems) to 85% after using IIoT. This progress was possible because of hands-on training, digital learning tools and real work experience. It shows that the workforce is getting ready to handle digital systems and data analysis.

ii. Smarter Decisions and Strategic Growth

BI and BDA helped teams make better decisions using real-time data and predictions. The main results were:

20% less time needed to make each product

66% fewer defects

iii. Better planning and supply chain management

Profit results also supported these findings. When comparing the old methods with the new BDA-BI-SP system (which includes skill development), profits went up by more than 80%. For example, making 50 products with the BDA-BI-SP approach gave an 89% profit increase, compared to only 39% and 48% with older methods.

These results show that using BI and BDA helps companies grow without losing quality or efficiency.

4.4 Conclusion

This study found that using Big Data Analytics (BDA), Business Intelligence (BI) and skill development (SP), together known as the BDA-BI-SP, leads to clear improvements in semiconductor packaging operations. The results showed that these tools helped reduce costs, improve efficiency and give better visibility into the supply chain across different stages of manufacturing, like dicing, die-attach and testing. A statistical analysis also showed that using these technologies improves product quality, with more defect-free units and higher customer satisfaction.

The introduction of IIoT (Industrial Internet of Things) and predictive analytics also helped teams make better decisions. These tools reduced mistakes, increased production output and improved overall profits—key goals for companies adopting Industry 4.0 practices. These findings reinforce the need for targeted talent development programs within the company that focus on digital competencies, data literacy and practical exposure to innovative manufacturing tools.

The research also pointed out the importance of improving workforce skills. Most people surveyed (88% said internships and apprenticeships were the best way to give students real-world experience. Others also supported industry-specific training and updating university courses to match current industry needs. These efforts are important for building a workforce with modern technologies like BDA, BI and IIoT. As the industry grows, it will be important to continue investing in technology, trainingand partnerships between businesses and universities to stay current and succeed.

CHAPTER V:

DISCUSSION

5.1 Discussion of Results

This chapter provides an in-depth analysis of the key findings from the results. It discusses their implications on workforce development, smart manufacturing and leadership within the semiconductor industry. It synthesizes the survey results, interview insights and methodology used in this study to identify systemic challenges related to academia-industry collaboration, workforce readiness and adopting Industry 4.0 technologies within the Indian semiconductor packaging sector.

The study adopted both quantitative surveys and qualitative survey by interviews to collect data from various related experts, including industry professionals, academic experts and policymakers. This methodology was essential in exploring the skill gaps, leadership challenges and the effectiveness of current collaboration efforts between academia and industry. The findings highlight the nature and extent of these challenges suggestings potential ways for transforming the semiconductor workforce to meet the sector's evolving needs.

5.2 Discussion of Research Question One

Discussion of Research Question One: How can BI and BDA improve operational efficiency, decision-making and quality control in Indian semiconductor packaging processes?

Two major schools of thought emerge from the analysis of the output of the study on business intelligence: the management and the technical. The managerial perspective on BI describes it as a process that draws on internal and external data sources to provide useful insights for management decision-making. On the other hand, the technical perspective sees BI as a set of resources that facilitate these activities, emphasizing data storage, retrieval, collecting and analysis technologies in semiconductor packaging manufacturing as a tool for efficient system life cycle design and administration, business intelligence relies on recognizing and comprehending desirable practices. When at hand, this information facilitates the swifter implementation of well-considered choices.

Source: Author

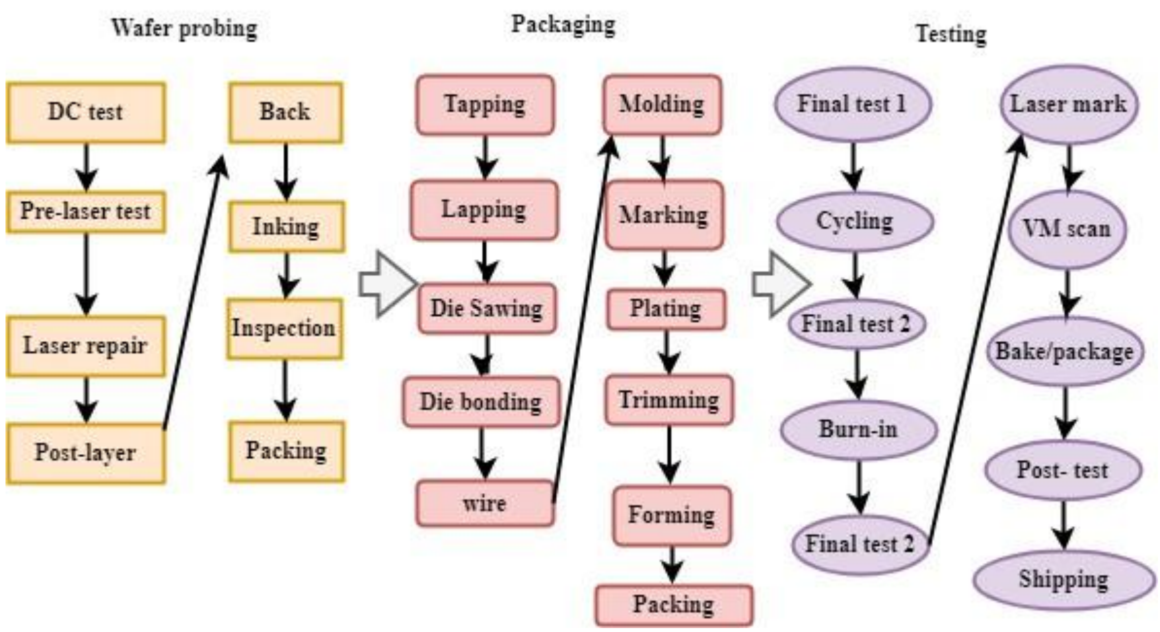

Figure 5.1
Process Flow in Semiconductor Packaging

Semiconductor Packaging Manufacturing Process:

The semiconductor backend packaging process is a crucial stage in the manufacturing of semiconductor devices. It bridges the gap between the raw silicon wafer and the finished product, which is later integrated into electronic systems. Packaging involves several key steps, some important ones include wafer dicing, die attachment, wire bonding, encapsulation and final testing. These stages ensure that the semiconductor components are physically protected and electrically connected in a way that allows them to function properly in consumer devices, computers, automotive systems and more.

1. Wafer Dicing: After the wafer has been fabricated, it is sliced into individual chips (dies) using precision sawing techniques.

2. Die Attachment: The next step is chips are attached to a package substrate using a high-precision adhesive.

3. Wire Bonding: Fine gold, Aluminium, or copper wires connect the chip to the package or substrate, allowing electrical signals to flow between them.

4. Encapsulation: The molding process follows, package is then encapsulated, typically through molding process into plastic or ceramic packages, to protect these delicate parts from environmental damage, physical stress and contamination.

5. Final Testing: Once packaged, the semiconductors undergo rigorous electrical testing to ensure their functionality and reliability before being sent to customers.

In semiconductor packaging, quality control, efficiency and cost-effectiveness are paramount. Even slight variations in the process can result in defects, reduced yields, or costly rework, which directly impacts the final product's quality and profitability. In India, semiconductor manufacturers in India, where the industry is evolving rapidly, optimizing the packaging process is crucial for enhancing operational efficiency, reducing costs and improving the competitiveness of the products in global markets.

The research carried out discusses about incorporating Business Intelligence (BI) and Big Data Analytics (BDA) into the semiconductor packaging process and how it can significantly improve the operational efficiency, decision-making capabilities and quality control in Indian semiconductor manufacturing.

- Operational Efficiency:

BI and BDA can help optimize production workflows in the semiconductor packaging line by collecting data and analysing at various stages of the manufacturing process, including die attachment, wire bonding and encapsulation. Manufacturers can streamline operations, reduce downtime and optimize equipment usage by identifying bottlenecks, waste and inefficiencies, leading to better throughput and reduced production costs. The study by (Xie, F. et al., 2021) applies clustering to match production capacity with demand based on the average input-output ratio. This helps to avoid overproduction or under utilization of the resources, making production processes more efficient. This aligns with the principles of Business Intelligence (BI) and Big Data Analytics in the semiconductor packaging industry in the research. Use of BI tools to analyze vast amounts of production data and this clustering method helps optimize resource allocation by matching production capacity to actual demand. This is especially useful in high-tech industries like semiconductor manufacturing, where production efficiency is critical. While the Integrated Feeding Control Strategy (IFCS) proposed by (Xie et al. 2021) offers significant potential to reduce production costs and improve efficiency, its practical application may be a challenge as due to infrastructure gaps, initial investment costs and the variability in raw materials in India.

i. Predictive analytics when used with BDA can forecast maintenance needs and predict machine failures even before they occur, minimizing unplanned downtime. This approach ensures that production schedules are addressed timely and equipment is kept in optimal condition.

ii. Improved Decision-Making: BI tools provide managers and decision-makers with real-time dashboards and reports that help monitor key performance indicators (KPIS) related to packaging processes, such as yield rates, cycle timesand defect rates. With access to up-to-date and accurate information, managers can make data-driven decisions for overall efficiency improvement of the packaging line.

iii.By analysing historical data, manufacturers can follow trends and patterns in production performance, adjust strategies, optimize workflows and allocate resources more effectively.

iv.Big Data Analytics can also support inventory management by ontime tracking of raw materials, components and supplies. This ensures that the right materials are available at the right time, reducing shortages. overstocking, which can impact production timelines and costs.

v.Quality Control: Quality control is one of the most important aspect of any manufacturing, same goes with semiconductor packaging. Even the minutest flaw or defect can lead to device failure in the end-user's product. By implementing BI and BDA, manufacturers can conduct real-time monitoring of the packaging processes, enabling them to detect and address defects at an early stage.

BDA allows the analysis of data from various sensors and testing equipment in real-time. By analysing the data, manufacturers can identify patterns and correlate them with defects or deviations from the optimal process parameters, allowing them to make adjustments to the production process before the defects occur.

Source: author

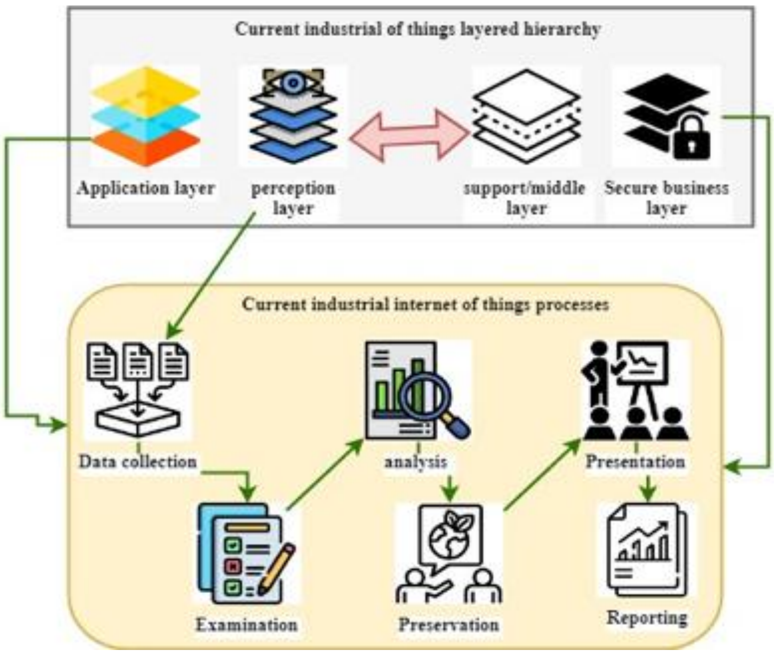

Figure 5.2:
Industrial Internet of Things (IIoT) in smart manufacturing

As shown in Figure 5.2, the completed products warehouse receives release directives based on real orders placed recently.

To evaluate the supply chain's profitability and customer satisfaction, it is necessary to keep detailed customer records. In semiconductor manufacturing, particularly in India, the supply chain for raw materials and specialized components (like silicon wafers, rare gases, bonding wires, solder pastes, epoxy molding compounds and chemicals) can be unpredictable and subject to external factors. The IFCS strategy by (Xie, F., et al., 2021) assumes a certain level of consistency in inputs and production conditions, but disruptions in the supply chain or variability in raw material quality could complicate the effective application of such a strategy. The material variability could undermine the benefits of integrated control, especially if the control systems cannot accommodate wide variations in input quality.

Importance of (IIoT) at various Manufacturing stages:

The research in this paper suggests the importance of Industrial Internet of Things (IIoT) integration for process efficiency (cycle time) and operational efficiency (throughput) across various semiconductor packaging manufacturing stages. The comparison between traditional and IIoT-enabled processes highlights significant efficiency improvements driven by automation, real-time monitoring and data-driven optimisations.

1. IIoT reduces cycle time across all semiconductor-packaging stages, with the most noticeable impact on Die Attach, Dicing and Plasma Cleaning.

2. Throughput is significantly higher in IIoT-driven processes, particularly in Dicing, Plasma Cleaning and Die Attach, indicating streamlined operations.

3. The combination of reduced cycle time and increased throughput improves overall semiconductor packaging efficiency, making IIoT adoption crucial for manufacturing.

4. The results highlight the role of automation, predictive maintenance and AI-driven analytics in optimizing process control and reducing downtime.

These findings suggest that IIoT-driven semiconductor packaging not only improves efficiency but also production reliability and scalability, making it a viable strategy for future semiconductor manufacturing.

According to Won et al. (2020), the adoption of factories with advanced technologies in SMEs is increasingly dependent on the use of data for decision-making. The integration of smart sensors, IIoT devices and big data analytics plays a critical role in making production processes more efficient, improving decision-making and reducing costs. This aligns with the idea that Business Intelligence (BI) and Big Data Analytics are vital tools for improving operational efficiency. In smart factories, data-driven decision-making is essential to optimizing the production process, reducing waste and enhancing product quality, which is similar to what is achieved in other sectors like semiconductor packaging, where BI tools and analytics can be used to monitor and optimize manufacturing processes.

The challenges outedlined in (Won et al. 2020) are similar to the obstacles faced when trying to integrate Business Intelligence and Big Data Analytics in any industry, including semiconductor manufacturing. Issues like a lack of skilled personnel, high initial investment costs and technological change are common across sectors. Therefore, skill development initiatives and organisational strategies are a must to ensure smooth adoption.

Del Giudice et al. (2022) discuss how small and medium manufacturing companies, through digital transformation, can become more adaptable and innovative. They propose a "self-tuning model," wherein businesses can adjust to changing conditions using digital tools. thereby helping them in addressing the use of digital technologies in shaping modern manufacturing. However, their research based on theoretical concepts and does not include any specific data or surveys while this study focuses on the semiconductor packaging industry in India and uses actual data collected from industry professionals and academic institutions. It examines how technologies like Business Intelligence (BI), Big Data Analytics (BDA) and the Industrial Internet of Things (IIoT) can improve performance, reduce delays and support better decision-making.

Another key point is that Del Giudice et al. briefly mention the need for businesses to change, but they do not go into detail about workforce skills or training. This study looks deeper into that area and finds a major gap between the skills taught in educational institutions and those required by the industry. It also shows the importance of stronger partnerships between universities and companies to help bridge this gap through better training, hands-on experience and updated course content.

In summary, while Del Giudice et al. give useful ideas about digital transformation, their work is mostly theoretical. This research adds to their ideas by focusing on a specific industry and using real data to provide clear suggestions for improving both technology use and workforce readiness in smart manufacturing.

- Operational and Financial Integration in Technology Adoption

The improvement of semiconductor packaging capabilities is influenced by industry research and the integration of Industrial Internet of Things (IIoT) technologies. There is a need for a balance between operational efficiency and financial sustainability. The study found that while there is potential for technological advancements which is recognized, many companies struggle to find sustainable financial models that support such investments

a. Smart Factories and Automation: The incorporation of IIoT into semiconductor packaging has allowed manufacturers to deploy automated systems capable of optimizing production lines. Some of these are Sensors, connected devices and data analytics enable factories to operate more efficiently, with predictive maintenance reducing downtime and improving yields. This level of integration accelerates the development of advanced packaging technologies.

According to Lee, H (2023), converging technology improves firm innovation competencies and business performance. The author agrees with the statement that convergent technologies can bring a change when the company adopts smart manufacturing, not only for advanced technologies but also leading to the success of firms. However, the limitation is that skill development and commercial aspects remain unaddressed.

b. Design and Simulation: Collaboration between academia and industry leads to more sophisticated software tools for simulating semiconductor package designs at the research level, incorporating real-world data from IIoT systems. This allows designers to test and move their designs patterns quickly, ensuring better performance and reliability before physical prototypes are made.

c. Data-Driven Decision Making: The use of IIoT in semiconductor packaging provides manufacturers with an abundance of data that can be analysed to optimize every aspect of the packaging process. From material choices to thermal performance, IIoT sensors gather critical information that help refine both design and manufacturing practices.

d. Sustainability: Both industry and academia are also collaborating to develop eco-friendly semiconductor packaging solutions which is important in today's time. The real-time monitoring capabilities with the help of IIoT can help reduce energy consumption and waste, making semiconductor packaging not only more efficient but also more sustainable.

Finally, these joint efforts have resulted in significant improvements in semiconductor packaging, with higher efficiency, reduced costs and more reliable products.

○ Quality results based on various methodologies:

The results on studying the quality aspect showed product flaws decreasing and reliability improving. Analytics aims to improve the overall quality of semiconductor packaging products. When combined with business intelligence and employee training, big data analytics may set businesses on a path toward creating cutting-edge technologies and delivering perfectly performed goods. Combining big data analytics magnifies this effect, providing predictive maintenance, quality control, for continous improvement. This method guarantees the accuracy and dependability of semiconductor packaging and gives production organisations the freedom to anticipate problems and develop improved solutions. Ultimately, this integrated approach not only moves the sector into the age of smart manufacturing but also positions it as a forerunner in providing goods of high quality.

Source: author

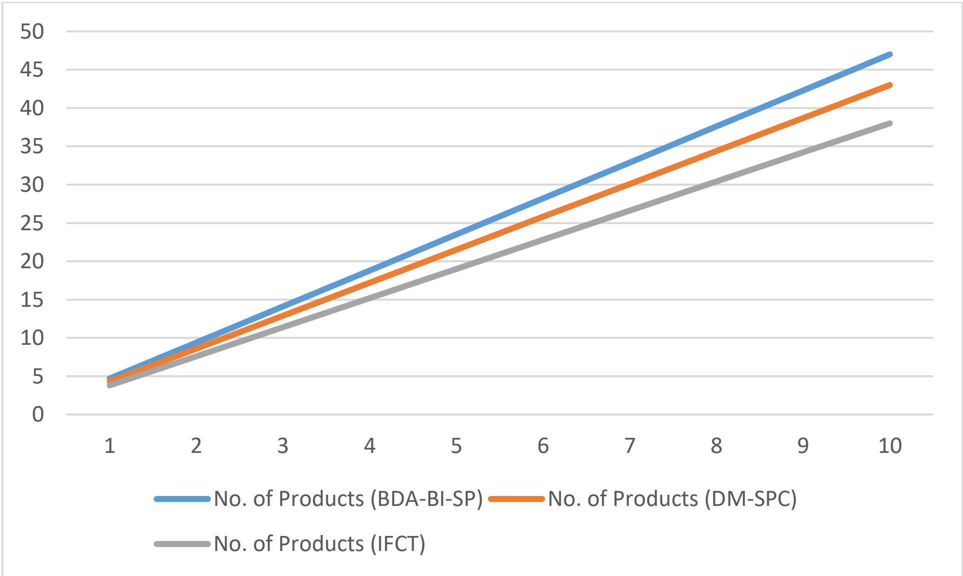

Figure 5.3
Regression Analysis: Quality Improvement Across Methods

Figure 5.3 illustrates the comparative quality improvements across three methodologies—BDA-BI-SP, DM-SPCand IFCT—based on regression analysis. Among them, BDA-BI-SP shows the highest correlation ($\beta_1 = 0.94$) between improved quality levels and the number of products meeting those levels, followed by DM-SPC ($\beta_1 = 0.86$) and IFCT ($\beta_1 = 0.76$). The number of products at varying quality levels was used as the dependent variable (Y), while the quality level percentage was the independent variable (X). The results indicate that the BDA-BI-SP method demonstrates the highest rate of quality improvement, as reflected by the regression coefficient ($\beta_1 = 0.94$), meaning for each unit increase in quality level, the number of products meeting that standard increases by 0.94 units.

The DM-SPC method also shows a strong correlation with quality improvements but at a slightly lower rate ($\beta_1 = 0.86$), suggesting that while it enhances product quality, it is not as efficient as BDA-BI-SP. The IFCT method has the lowest rate of improvement ($\beta_1 = 0.76$), indicating a slower progression in achieving higher quality levels compared to the other two methods

Regression Equations for Each Method

Each method's performance was modelled with a simple linear regression equation:

- BDA-BI-SP: $Y = 0.94X + C_1$
- DM-SPC: $Y = 0.86X + C_2$
- IFCT: $Y = 0.76X + C_3$

Here, C_1, $C_2$and C_3 represent the baseline quality output when quality level (X) is zero.

i. Interpretation of Results

The regression analysis shows that the BDA-BI-SP method improves product quality the best. Its coefficient is 0.94, which means that for every 1% increase in quality, the number of good (conforming) products goes up by 0.94 units. The DM-SPC method comes next with a coefficient of 0.86and IFCT follows with 0.76, showing a slower improvement. These numbers help us understand how effective each method is at improving quality.

ii. Discussion of Regression Results

As seen in Figure 5.3, the BDA-BI-SP approach performs better than the other methods. It uses real-time data and predictive tools to help improve production. This leads to better quality control, faster decision-making and fewer product defects, which helps the whole process run more smoothly.

On the other hand, DM-SPC still uses traditional quality control methods, which work well but don't adapt in real time like BDA-BI-SP. Similarly, IFCT is organised and follows a system, but it doesn't predict or fix problems ahead of time, so it doesn't improve quality as much.

These results show that using smart analytics tools like BDA-BI-SP in semiconductor packaging is important. It helps keep product quality high, reduces waste and helps companies stay competitive in a fast-changing industry.

iii. BDA and BI Performance

While traditional methods like Design of Experiments (DM), Statistical Process Control (SPC) and Integrated Flexible Control Techniques (IFCT) have helped improve manufacturing processes and product quality, they mainly rely on historical data and are more reactive. These methods often require advanced technical knowledge, making them harder for lower-skilled workers to use effectively.

In contrast, Business Intelligence (BI) and Big Data Analytics (BDA) offer a more modern, predictive and user-friendly approach. These technologies are not limited to management—they help employees at all levels to engage with data, spot problems early and reduce defects during production.

According to Gaardboe et al. (2018), the success of BI systems depends on how well they are integrated into existing infrastructure and aligned with the organisation's goals. While that study explains what makes BI systems effective, it does not directly focus on how smart manufacturing strategies are applied. This research builds on that by exploring how BI and BDA help manufacturers stay competitive and sustainable, not just through data analysis, but also by supporting ongoing employee learning and development. These tools allow workers to quickly improve their skills and apply new knowledge, leading to better efficiency, higher qualityand stronger long-term performance.

Qu et al., (2021) also points out the importance of skilled workers in reaching high manufacturing efficiency and product quality. This supports the current study's argument that human capability must grow alongside digital technology. By combining BI and BDA with workforce development, companies can create a continuous learning environment where employees make better decisions and easily adapt to new tools and methods.

The findings of this research support and expand on previous studies by showing that BI provides real-time insights and better planning. At the same time, BDA adds predictive analytics and live system monitoring. When used together, they help companies improve production processes, reduce risks before they become seriousand respond faster to market changes.

Unlike earlier studies, which mostly focused on improving production numbers, this study also highlights the role of human skills and digital tools in collaboration.

Jwo (2021) explores how people and smart machines can work together in modern manufacturing environments. The study focuses on “human-in-the-loop” systems, where humans still play an important role in guiding and controlling machines that use technologies like artificial intelligence (AI). One of the key points in Jwo’s research is the importance of data protection. As factories become more digital, keeping sensitive information safe such as company data or customer details becomes a serious concern.

While Jwo mainly looks at the interaction between humans and machines and the issue of data security, this study focuses more on how digital technologies such as Business Intelligence (BI), Big Data Analytics (BDA) and the Internet of Things (IIoT) improve production performance in the semiconductor packaging industry in India.

A key difference is that Jwo’s study has no mention of skill development or workforce training in detail while this research highlights a major skills gap in the industry, especially in the use of advanced technologies like automation and data analysis. It also shows the need for stronger collaboration between academic institutions and companies to provide hands-on training and update educational programs to meet industry requirements.

In summary, Jwo (2021) provides useful insights into how humans and machines can interact and the importance of protecting data in smart manufacturing. This study adds a different perspective by focusing on the practical use of digital technologies in production and the urgent need to develop a skilled and job-ready workforce. Both studies agree that people play a key role in smart manufacturing, but this research puts more focus on preparing them with the skills needed to succeed.

Finally, this research shows that BI and BDA are not just used for looking at data, but are also important for helping the whole company improve. When these tools are used the right way, they can support new ideas, better system connections and smarter decision-making. This is especially useful for companies in the semiconductor industry, as it helps them stay strong and competitive in the global market.

Source: author

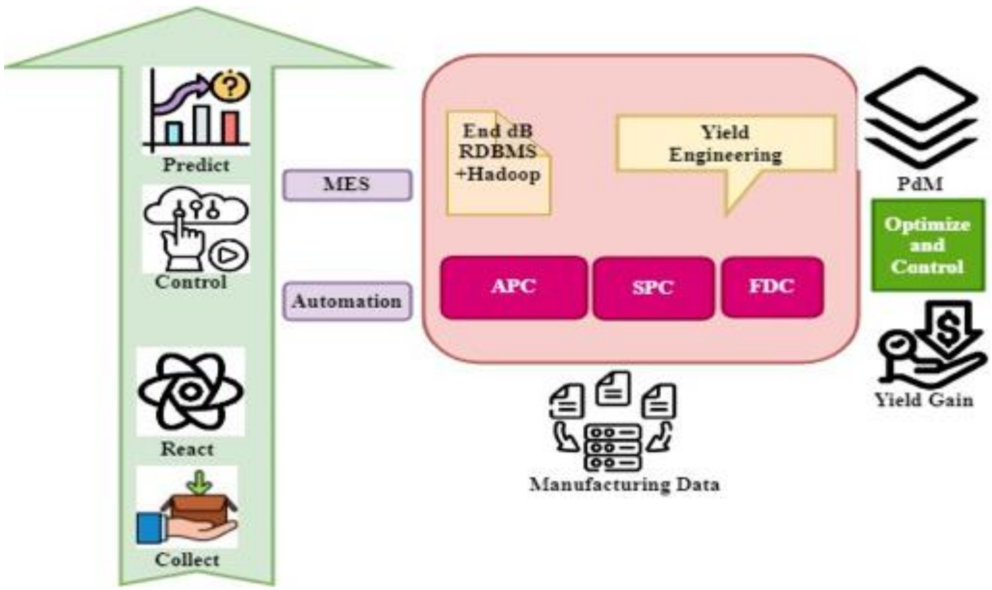

Figure 5.4:
Big Data in Semiconductor Packaging

Figure 5.4 shows that the production of semiconductors is a multi-stage process that has become more sophisticated and technologically demanding with each successive generation of devices. However, the margin for error in the process has steadily shrunk. Significant developments in sensor-based data collecting and metrology technologies have resulted from the demand for robust and optimum procedures within a short period. This, together with increased accessibility and lower storage costs, has provided engineers with a wealth of information to mine through big data analysis. Exploring new technologies and refining processes to boost production and quality are needed to exploit this important data effectively.

The sheer volume of information produced every day in semiconductor production facilities highlights the relevance of streamlined data collection, storage, distribution and analysis. Using data effectively is crucial in finding avenues to raise output, boost quality and cut expenses.

Data volume is increasing at a rapid rate in the semiconductor manufacturing industry, as it does in many others, necessitating new approaches to data management that improve accessibility, speed and quality. This has facilitated the company-wide adoption of big data initiatives. The International Technology Roadmap for Semiconductors (ITRS) identifies five critical characteristics of the big data challenge: volume, velocity, variety, veracity and value. Using these, extracting value from data is considered the most important outcome. This is supported by (Verma et al., 2019), who emphasised the growing demand for professionals capable of combining domain expertise with analytical tools to help generate actionable insights from complex datasets. As (Verma et al., 2019) mentions, that data volume in the semiconductor industry as other Electronics sector is increasing rapidly, making it necessary to adopt advanced data management strategies. Both recognize the increasing importance of data analytics as an important factor in driving business performance and ultimately making actionable decisions.

In relation to semiconductor packaging, the application of big data analytics is not merely an operational advantage but an important one making strategic decisions. BDA facilitates real-time defect prediction, root cause analysis and process optimisation capabilities that are particularly vital in an industry defined by tight tolerances, rapid technological evolution and global competition.

Source: author

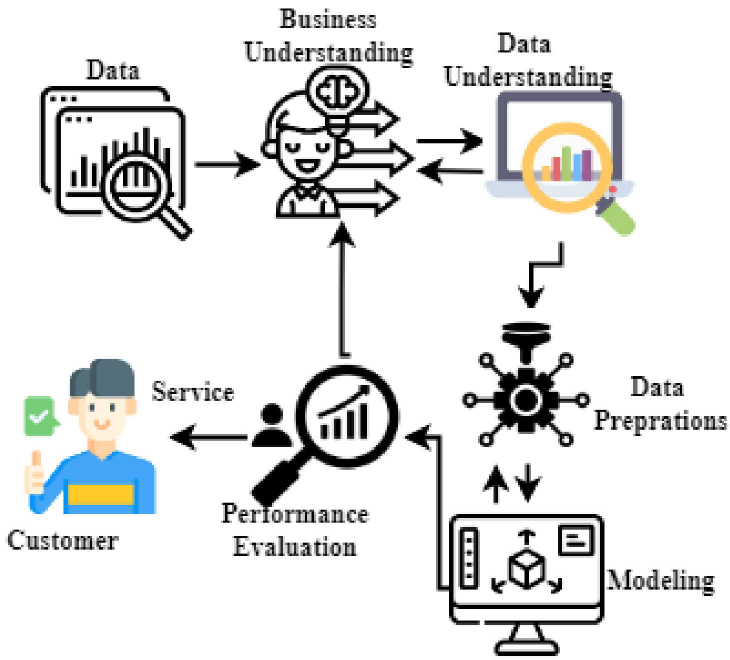

Figure 5.5:
Big data-based business intelligence service

As illustrated in Figure 5.5, the implementation of Business Intelligence (BI) systems has shown an important role in transforming raw, fragmented data into structured, actionable inputs that support strategic decision-making.

Within the context of semiconductor packaging and manufacturing, BI systems enable organisations to integrate diverse data sources, including customer response, order processing, production data, supply chain activities and financial metrics, into a unified analytical data. This gives decision-makers a comprehensive and real-time understanding of both operational performance and market dynamics. The advantage of BI tools is that they deliver timely, relevant inputs, thereby helping the organisation forecast upcoming business opportunities, identify process inefficiencies and make informed decisions that contribute to sustainable growth.

Thus, in the context of present manufacturing environments, business intelligence is not merely a supportive tool but a strategic enabler of efficiency, agility and competitiveness.

5.3 Discussion of Research Question Two

How does the collaboration between academia and industry in India's semiconductor packaging manufacturing sector impact the skills gap, talent development and alignment of educational offerings with the industry's evolving needs?

The survey responses from academia and the semiconductor industry in India highlight a significant gap between educational offerings and industry demands, particularly in the semiconductor application of covering the packaging and delivery aspects of the semiconductor sector. This study explores the skill gaps within India's semiconductor packaging workforce and examines how academia and industry can help bridge these gaps, ultimately contributing to the development of a skilled workforce for smart manufacturing. The survey results indicate a notable discrepancy between the academic curricula offered by educational institutes and the skill requirements as per the semiconductor industry in India. While universities have started incorporating courses relevant to semiconductor manufacturing, the lack of practical exposure and hands-on experience is limited or none. Only a small fraction of academic institutes provide industrial training or have partnerships for apprentices.

From the industry's point of view, the ability to adapt to new technologies having related technical skills and strong problem-solving abilities are important for new hires. While companies understand the importance of these technologies, there is a clear shortage of candidates with specific training in areas like automation systems, machine learning and data analysis. Many companies offer training, but it's usually only when necessary and fewer provide complete training programs. This highlights the need for educational institutions to include these skills in their courses to better prepare graduates for the changing industry.

The survey responses also suggest that closer collaboration between academia and industry could help solve these problems..

The survey suggests that collaboration between universities and companies could help address these issues. Universities can improve their programs by adding related courses on new technologies and creating more opportunities for practical training, like apprenticeships, works or industry projects.

At the same time, companies should offer more training for both faculty members and new employees. Regular workshops and more comprehensive training programs for recruits would help ensure that employees are better prepared to work with advanced technologies in semiconductor manufacturing.

Institutions can improve their programs by adding courses on advanced manufacturing technologies, setting up apprentice programs and creating research opportunities in areas like AI and advanced semiconductor-packaging technologies.

To support India's growth in this high-tech collaboration between both sectors can better prepare students for the changing semiconductor industry, ensuring a skilled workforce.

From Industry side, companies to come forward offering programs to help faculty develop their skills, holding regular workshops periodically and providing thorough training for new hires.

- Current Skill Gap Versus Industry Demands

The survey results highlight a significant gap between the skills acquired by fresh graduates and the evolving demands of the semiconductor packaging industry. Despite growing demand for expertise in packaging technologies, process engineering and AI/ML integration, many new entrants to the workforce are underprepared in terms of practical exposure. While theoretical instruction in institutions is gradually expanding, with courses such as VLSI Design and Semiconductor Nanotechnology, hands-on training remains inadequate. As a result, graduates often lack experience with advanced tools, equipment troubleshooting and process optimisation skills considered essential in semiconductor manufacturing environments.

New recruits frequently struggle to meet expectations due to limited real-world exposure. The need for adaptability as soon as possible to the technological advancements in production houses increases the importance of bridging the academic-industry gap. These findings emphasize the necessity for institutions to align academic curricula with real-world industrial requirements and for industries to expand structured internship and apprenticeship opportunities.

i. Skill Development for a Future-Ready Workforce

To effectively adopt Industry 4.0 technologies such as Business Intelligence (BI), Big Data Analytics (BDA), and the Industrial Internet of Things (IIoT), India's semiconductor workforce must be equipped with new-age technical competencies. The survey highlights the importance of continuous upskilling, including hands-on workshops, conferences, exposure factory visits and stronger partnerships between academia and industry.

Three key skill areas stand out:

i. Technical Proficiency**:** The workforce needs to be skilled in using BI tools, analysing big data, and working with automated systems. Ongoing training in automation, machine learning, and data analytics is essential in smart manufacturing settings.

ii. Adaptability**:** As semiconductor manufacturing technologies evolve quickly, workers must be flexible and open to learning. Lifelong learning and regular skill updates are necessary for effectively integrating AI, BDA and other advanced systems into packaging processes.

iii. Analytical and Problem-Solving Skills: As packaging processes grow more complex, the workforce must be capable of analyzing issues, optimizing processes and supporting quality control measures. These skills are vital to innovation and process efficiency.

Moshiri et al. (2020) discuss how Industry 4.0 concepts can be applied in tooling production using a smart manufacturing system with metal additive manufacturing. They emphasize the benefits of a fully digitalised, modular production system, where production can be decentralized and managed remotely from a central location. This method brings production closer to customers or suppliers, making it more efficient and practical. They also emphasize that adopting Industry 4.0 technologies requires a change in mindset, because even if the technology works well, the system can fail if the people using it aren't prepared for the changes.

While Moshiri et al. (2020) emphasise the importance of Industry 4.0 technologies, this research also highlights the need for workforce training and upgrading skills. Additionally, Moshiri et al. focus mainly on the technological aspects of Industry 4.0, while this research also examines how these technologies affect operational performance, such as cycle times and decision-making. Both studies agree that successful implementation depends not only on technology but also on the readiness of the people using it.

- Training Duration and Readiness of New Recruits

The survey shows that while long training programs (up to 90 days) help new employees learn about semiconductor processes, these extended onboarding periods slow down their ability to contribute effectively. During this time, companies spend money on training without seeing immediate results, which can impact profitability and operational efficiency. To solve this problem, companies could shorten training periods to 2–4 weeks and provide foundational training before employment or work with academic institutions for joint training programs. This would lower costs and help new employees start contributing to production roles more quickly.

These findings resonate with the work of Chenoy et al. (2019), who advocate for fast, targeted skill development under the ‘Make in India’ initiative. Their research emphasises equipping workers with new-age manufacturing competencies including digital literacy, automation and process control within shorter timeframes to maintain competitiveness globally.

- Automation as a Strategic Priority

The research shows that there is a clear shift towards automation in Indian semiconductor packaging companies, especially in production and quality control areas. In the next one to three years, these companies plan to invest heavily in automation technologies to enhance operational efficiency, improve process accuracy and increase production output. This shift is driven by the increase in complexity and competitiveness of semiconductor packaging, especially in advanced methods where automation plays a critical role in reducing human error and improving yield rates.

These findings agree with the ideas presented by Lin et al. (2021), who suggest a method for evaluating the development of smart manufacturing systems. Their approach focuses not just on adding automation technology, but also on the need for ongoing improvements, adaptability and alignment with the company's overall strategy. Although their work is not specific to semiconductor packaging, it is relevant in demonstrating that short-term automation must be part of a longer-term vision of capability development and system evolution.

The present study reflects a practical, operational focus among Indian firms, prioritizing near-term gains in efficiency and quality. However, with Lin et al.'s (2021) conceptual framework, it becomes evident that successful digital transformation also requires sustained investment in internal capabilities, such as workforce readiness, adaptive leadership and system scalability, to fully realise the long-term benefits of automation

- Challenges in adopting AI, Machine Learning and Automation

Despite the strong intent to automate, the research highlights a major constraint: the lack of skilled human capital to support and manage emerging technologies such as artificial intelligence (AI), machine learning (ML) and automation. Many firms do not find right employees with technical competencies necessary to operate, maintain and optimize these technologies. This presents a twofold challenge for companies: they need to invest in advanced technology while also putting resources into training and upskilling their workforce.

These findings are consistent with those of Alharbi M, (2022), who stresses the importance of comprehensive skill development for engineers entering Industry 4.0

environments. Alharbi M, (2022) argues that, be critical thinking, communication and leadership are essential for navigating the interconnected and dynamic nature of smart manufacturing systems.

Survey responses focus on short-term automation to increase efficiency and product quality, primarily aimed at improving operational metrics like yield and throughput. Lin et al. (2021) provide a long-term strategic plan, emphasising dynamic capabilities and adaptive leadership to manage intelligent manufacturing transformations, with a focus on scalability and continuous improvement. On top of that, companies have trouble integrating new automation systems with older equipment, making the whole process more expensive and complicated.

- Implications in the semiconductor packaging industry

The Indian semiconductor packaging industry is at a critical juncture. While companies actively invest in automation to meet immediate performance and quality objectives, the study reveals that long-term competitiveness will depend on parallel investments in workforce development, leadership capability and sustainable practices.

The research contributes to the broader discourse on Industry 4.0 by optimisation the importance of aligning technical transformation with strategic human resource development. By synthesizing dynamic capability theory (Lin et al., 2021), sustainable leadership practices Alharbi M, (2022) and innovation leadership (Guzmán et al., 2020), this study provides a comprehensive model for the Indian semiconductor packaging sector to transition successfully into a smart, sustainable and globally competitive industry.

The perspectives of Lin et al., (2021), Alharbi M, (2022) and (Guzmán et al., (2020), this study optimisation the multifaceted role of leadership in ensuring the success of automation and smart manufacturing initiatives. Lin et al. (2021) gave importance to structural and strategic adaptability, while Alharbi M, (2022) prioritises ethical and sustainable leadership and Guzmán et al. (2020) advocate for transformational leadership that drives innovation through change management.

Current research bridges these strategies by identifying emotional intelligence, communication and workforce empowerment as the missing links connecting strategic vision with on-the-ground implementation. In high-tech environments such as semiconductor packaging, where complexity is high and change is constant, leadership must be both technically competent and emotionally intelligent, capable of guiding innovation through empathy, clarity and collaboration.

- Semiconductor Industry Strategy

This study looks at strategies for semiconductor manufacturing and compares them with the work of Opazo-Basáez et al. (2023) in a few important ways. Both studies agree that a complete approach is needed to improve profitability and stay competitive. However, they differ in their focus and the strategies they recommend. The following discussion compares and contrasts these two perspectives across various aspects:

a. Focus on Long-Term Sustainability

Both this study and Opazo-Basáez et al., (2023) highlight the importance of building long-term sustainability. In semiconductor manufacturing, sustainability goes beyond technological advancements. This study focuses on setting up optimization procedures, improving product quality and building a foundation for long-term profitability. Similarly, Opazo-Basáez et al. (2023) highlight the importance of financial models that are sustainable and can support growth and flexibility in response to market changes.

While both studies agree on the necessity of sustainability, there is a difference in the approach: this study places more emphasis on operational improvements such as quality control and process standardization, whereas Opazo-Basáez et al., (2023) stresses the importance of firm financial planning and cost-benefit evaluations to ensure long-term stability.

b. Improvement in Efficiency and Quality

Improving efficiency and product quality is an important focus of this study. It explains how using new technologies, improving processes and standardizing methods can make operations more efficient and improve product quality. Similarly, Opazo-Basáez et al. (2023) argue that having strong financial models is important to support these improvements. They highlight the need for financial foundation ensuring that investments are well-directed and resources are allocated to projects that maximize returns.

While both studies agree on the importance of continuous improvement, the primary difference lies on financial sustainability. Opazo-Basáez et al., (2023) highlight the importance of cost-benefit analysis to ensure that improvements in efficiency and quality are not just practical solutions but also financially sound. In contrast, this research focuses more on the operational aspects of efficiency and quality rather than the financial side.

c. Financial Implications

Opazo-Basáez et al. (2023) take a financial approach, focusing on the financial impact of investing in new technologies. They consider both direct and indirect costs, along with the risks and benefits of adopting new technologies. Their approach helps decision-makers balance costs and expected benefits when making technology choices.

In contrast, this research doesn't discuss financial strategies in detail. Its main focus is on using technologies to improve processes and product quality rather than examining their financial impact. While it recognises the goal of increasing profitability through technology and quality improvements, it doesn't explore the financial analysis of each investment in depth.

d. Broad vs. Specific Contexts

This research focuses on the semiconductor industry and looks at the practical application of technological advancements and quality control as part of a broader strategy to increase competitiveness. The study is specifically concerned with how operations, technology and product quality improvements can lead to a sustainable competitive advantage and profitability in semiconductor manufacturing.

Opazo-Basáez et al. (2023), on the other hand, takes a broader, more optimisation approach. Their financial model applies to various industries, not just semiconductors. They provide an optimisation approach to technological investment decisions and the integration of financial strategies across different sectors, whereas this study is focused on semiconductor packaging manufacturing.

e. Integrating Operational and Financial Strategies

To develop a comprehensive strategy for semiconductor manufacturing or any high-tech industry. It is therefore important to integrate both operational improvements and financial evaluations. This research addresses the operational parameters, focusing on the adoption of new technologies, process optimization and product quality enhancement. However, the approach by Opazo-Basáez et al. (2023) offers valuable insights into technological investments, thereby aligning it with long-term financial sustainability.

By combining both perspectives, semiconductor companies can create strategies that improve productivity and operational efficiency and ensure that investments are financially viable in the long run. Integrating operational improvements with sound financial models can lead to sustained growth, profitability and competitiveness.

5.4 Summary of Findings

This research emphasises using automated technologies like BI, BDA and IIoT in semiconductor packaging. These technologies help improve efficiency, decision-making and quality control. Implementing these technologies, combined with industry-academia collaborations to bridge skill gaps, positions India's semiconductor packaging sector for long-term success in the manufacturing sector of semiconductor packaging in the Indian market.

As the semiconductor industry in India begins a new area of growth, adopting these modern technologies will improve operational efficiency and support the industry's ability to meet global standards of quality and competitiveness.

The integration of these components can provide several important benefits:

a. Operational Efficiency: By using real-time monitoring data analysis with Band BI, operations become more efficient. This helps increase yield, reduce waste and maintain high-quality standards in semiconductor packaging.

b. Innovation: A skilled workforce is important for driving innovation, as they can quickly adapt to new technologies. Combining automated processes with advanced technologies ensures that the Indian semiconductor packaging industry stays up-to-date with global trends to remain competitive.

c. Scalability: As the semiconductor industry continues to expand, the integration of BI, BDA, IIoT and workforce skill development provides the scalability needed to meet increasing demand. The workforce's ability to manage increasingly complex systems ensures long-term sustainability and strengthens the competitiveness of the Indian semiconductor industry

The results show that the BDA data-driven and BI technologies will help semiconductor packaging, positioning India's industry for success in an increasingly data-driven and technologically advanced manufacturing landscape.

The study also found a big gap between what students learn in colleges and what the semiconductor packaging industry in India actually needs. Although some universities have started teaching subjects like Design and Semiconductor Nanotechnology, students still do not get enough practical experience. For example, only a few colleges allow students to work with real machines or do hands-on packaging-related projects. This leaves graduates unprepared for actual jobs in the industry.

The study found that many companies are now focusing on automation and smart manufacturing using technologies like Artificial Intelligence (AI), Machine Learning (ML) and Big Data Analytics (BDA). But most new employees do not have the skills to work with these tools. For instance, companies said that while they want to use machine learning to predict equipment failures, most graduates don't know how to work with such systems.

Another key issue is the time it takes to train new employees. Many companies said that they need up to 60 to 90 days to train new hires because they lack job-ready skills. This delay adds to company costs. Some businesses suggested that if students had better training before joining—like internships or short job-based courses—they could be productive sooner. For example, companies reported that students who had done internships in similar environments were able to perform better and needed less training.

The research also showed that technical knowledge alone is not enough. Companies are looking for people who can solve problems and quickly learn new technologies. For example, workers need to know how to use smart sensors on machines or fix issues when a process goes wrong, but most students are not trained for this kind of real-time problem-solving.

Finally, the study stressed the need for better partnerships between colleges and companies. Right now, only a few universities work closely with the semiconductor industry by offering apprenticeships, doing joint research, or developing special training programs. Where such partnerships do exist, students get better training and companies are more satisfied with their new employees.

The comparison study below highlights key insights, methods and impacts from the various studies in the literature review. These references cover critical aspects of the semiconductor industry, including smart manufacturing**,** leadership competencies**,** supply chain optimisation and technological advancements in packaging**.**

Source: author

Reference	Focus Area	Key Findings	Key Technologies	Impact on Semiconductor Industry
Mohammed M.A et al., 2020	Smart Manufacturing & Technological Leadership	Investigated skills needed for technical management and sustaining smart manufacturing; leaders play a vital role in fostering smart manufacturing.	Smart Manufacturing, Leadership, Industry 4.0	Identifies the need for capable leadership to manage technological transitions for semiconductor manufacturers to stay competitive and innovate.
Giudice M.C et al., 2021	Agility in Small & Medium-Sized Businesses (SMEs)	SMEs in manufacturing are adopting Industry 4.0, demonstrating a balance between exploration and	Industry 4.0, Digital Innovation	Highlights the need for agility in adopting Industry 4.0 in semiconductor SMEs, allowing them to innovate

		exploitation in digital systems.		and respond to market changes more efficiently.
Tzu-Chieh Lin et al., 2021	Dynamic Capabilities in Manufacturing	Developed a dynamic capability-based methodology for evaluating maturity in smart manufacturing transformations, emphasizing the need for flexibility and agility in manufacturing.	Dynamic Capabilities, Maturity Models	Addresses how semiconductor manufacturers can build the required capabilities to adapt to rapidly changing markets and technologies, improving competitive advantage and adaptability.
Jung-Sing Jwo et al., 2021	Human-in-the-Loop for Smart Manufacturing	Explored the integration of human expertise and BDA/AI in manufacturing, focusing on enhancing interaction between workers and machines in production environments.	Human-in-the-Loop, AI Integration, Smart Factories	Aims to improve collaboration between workers and smart machines, critical for optimizing semiconductor production lines and achieving Industry 4.0 objectives.
Guzmán et al., 2020	Leadership in Industry 4.0	Focused on the role of leadership competencies in Industry 4.0, outlining essential cognitive, interpersonal, business and strategic competencies for future leaders in semiconductor industries.	Leadership, Industry 4.0, Competency Development	Stresses the importance of strong leadership in the semiconductor sector, helping companies manage the transition to smarter, more automated manufacturing environments.
Kalsoom T. et al., 2020	Smart Manufacturing & Sensor Integration	Identified the gap between traditional and smart factories, highlighting the	Sensors, Smart Manufacturing, Automation	The study's findings show that integrating advanced sensors

		importance of low-cost sensors for achieving optimal manufacturing performance.		in semiconductor production can lead to higher efficiency and better quality control.
Won JY et al., 2020	Industry 4.0 and IT Integration	Focused on how the adoption of information technology can improve production capabilities during the Fourth Industrial Revolution.	IT Integration, Industry 4.0, Automation	Emphasises the need for semiconductor industries to invest in advanced technologies to stay competitive and achieve optimal performance, which is crucial for meeting the growing global demand.
Fernando E. García-Muiña et al., 2020	Sustainability in Business Models	Investigated the shift to sustainable business models and the impact on financial performance and environmental responsibility in semiconductor manufacturing.	Sustainable Business Models, Economic Impact	Highlights the increasing importance of eco-friendly business strategies in semiconductor production, aligning with global sustainability trends and consumer preferences.
Lee H et al., 2023	Convergence of Technologies in Smart Manufacturing	Explored the integration of diverse technologies in smart manufacturing and its impact on financial performance, showing the benefits of technological convergence in production systems.	Technology Convergence, Financial Performance	Explores how the introduction of technologies, ican enhance operational efficiency and profitability, which is critical for semiconductor manufacturers looking to optimize production.

Tejasri B. et al., 2023	Semiconductor Trade & Economics	Analysed the role of India in the global semiconductor supply chain, including import/export data and its growing importance in the sector.	Big Data, Supply Chain, Import/Export Analysis	Provides insight into global trade patterns in semiconductors and how India is becoming a significant player in the supply chain, with implications for production capacity and international trade dynamics.
Tan C.L. et al., 2023	Blockchain & Supply Chain Integration	Focused on blockchain's role in improving supply chain visibility and integration, suggesting its potential to optimize semiconductor manufacturing.	Supply Chain Integration	Offers insights into how blockchain could be used to enhance transparency and traceability in the semiconductor supply chain, reducing risks and improving efficiency.
Xie F. et al., 2021	Integrated Feeding Control Strategy (IFCS) for Production	Analysed data to reduce production cost by optimizing equipment /process changes in semiconductor manufacturing.	IFCS /BDA/ Production Optimisation	Focuses on reducing production costs in semiconductor manufacturing, helping companies streamline production and improve operational efficiency.
Hariharan A.N. et al., 2021	Economic Growth and Regional Semiconductor Exports	Investigated the economic factors driving semiconductor export income, highlighting regional factors and labour force development in India.	Regression Analysis, Economic Factors	Demonstrates how factors like a trained workforce are key drivers for regional growth in the semiconductor sector, with implications for policy-making and

				investment strategies.
Li Z. et al., 2021	Smart Technology in Production Line Management	Discussed using intelligent technologies to optimize the semiconductor production line, improve quality and reduce production costs.	Smart Technology, Production Line Management	Addresses how intelligent technology can streamline semiconductor production, ensuring higher efficiency and better adaptability to market demands.
Tripathi V. et al., 2022	Sustainable Production Management System	Proposes a strategy for sustainable manufacturing in Industry 4.0 using intelligent systems to enhance operational excellence in the semiconductor sector.	Intelligent Systems, Sustainability, Operational Excellence	Focuses on improving sustainability in semiconductor manufacturing, enabling companies to reduce waste and improve long-term operational viability.
Gajdzik B. et al., 2022	Competencies for Industry 4.0 Workforce	Developed a framework for employee competencies in Industry 4.0, emphasizing the skills needed for workers in smart manufacturing environments.	Workforce excellence, Industry 4.0	Highlights the increasing importance of eco-friendly business strategies in semiconductor production, aligning with global sustainability trends and consumer preferences.
Park I.B. et al., 2021	Deep Reinforcement Learning in Semiconductor Packaging	Introduced a deep reinforcement learning approach for job scheduling in semiconductor packaging, improving efficiency	Deep Reinforcement Learning, Semiconductor Packaging	Demonstrates how machine learning techniques can enhance semiconductor packaging processes, optimizing

		and reducing computing time.		production scheduling and reducing operational costs.
Kim M.S. et al., 2021	Microstructural Features in Ultrasonic Bonding	Studied the microstructural features of ultrasonic bonding surfaces in semiconductor packaging, aiming to improve the quality and longevity of the packaging.	Ultrasonic Bonding, Microstructural Analysis	Contributes to the development of more reliable and durable semiconductor packaging techniques, which is critical for maintaining the performance of semiconductor products over time.
Lee L.C. et al., 2021	High-Density Fan-Out Technology in Packaging	Investigated new technologies in semiconductor packaging, focusing on multi-layer stacking and warpage control during packaging.	Fan-Out Technology, Semiconductor Packaging	Helps improve the reliability and performance of semiconductor packaging, especially in high-performance computing applications, which is essential as devices become more complex.
Sahoo K. et al., 2021	Physical Layer Optimization in Processors	Developed a method for optimizing the physical layer in semiconductor processors, with an emphasis on electrical factors and production costs.	Physical Layer, Processor Design	Enhances semiconductor manufacturing by optimizing the physical layers, which directly impacts the efficiency and performance of

Table5.1
Comparison Key Findings and Concepts in Semiconductor Industry

To sum up, the Indian semiconductor packaging industry can grow and stay competitive if it uses the right technology and trains people properly. Using BI, BDA and

IIoT has already made operations faster and better. But for long-term success, the industry must also invest in people through better education, regular training and closer ties with academic institutions. This combination of technology and talent is key to making smart manufacturing successful in India. Further, the work of Chenoy et al. (2019) on skill development in the context of the "Make in India" initiative relates to the second part of this research on the skills gap in India’s semiconductor sector. They stress the importance of ‘new-age’ skills such as AI, automation and analytics, which this study also identifies as essential.

Source: author

Business Area	**Actionable Insight**
Operational Strategy	Automate using AI/BDA; Invest in predictive maintenance and smart scheduling systems.
Leadership & Talent	Upskill workers for Industry 4.0; Emphasise leadership adaptability and digital literacy.
Supply Chain	Implement blockchain and analytics for visibility; Diversify regionally (e.g., India).
Innovation & IP	Invest in next-gen packaging, acquire or partner with SMEs.
Sustainability	Investigate into product lifecycle; track and report KPIs; shift to circular economy models.
Growth & Expansion	Explore government incentives; align strategy with regional tech capabilities and policy.

Table 5.2
Business Perspective

The investment in training programs and skill enhancement initiatives has positioned the workforce to equip them with the complexities of BI and big data analytics and established a culture of continuous learning. This helps the trained workforce, who are better prepared to work on emerging technologies, supporting the faster move for adaptation for sustained success. As the semiconductor sector continues to evolve, integrating BI, big data analytics and skill development stands for continued innovation, competitiveness and resilience within the semiconductor packaging industry in India. The amalgamation of BI, analytics and skill development has optimized current operations and laid a robust foundation for the industry's future growth and technological leadership.

CHAPTER VI

SUMMARY, IMPLICATIONSAND RECOMMENDATIONS

6.1 Summary

This thesis focused on exploring how technologies like Business Intelligence (BI), Big Data Analytics (BDA) and the Industrial Internet of Things (IIoT) can help improve the semiconductor packaging industry in India. The research aimed to show how these technologies can improve efficiency, decision-making, production errors and overall efficiency to keep businesses competitive in a fast-evolving market.

The study used case analysis and secondary data review to understand current practices. The findings showed that BI, BDA and IIoT support real-time monitoring, predictive insights and better resource use. These tools help companies quickly spot problems in production, measure performance and make faster decisions. This leads to improved product quality, reduced costs and increased operational efficiency.

Another key area the thesis explored is the role of academic-industry collaboration in developing skilled professionals. it was found that strong cooperation between universities and businesses helps make education more relevant to industry needs. This ensures that graduates are better prepared to work with new technologies and support smart manufacturing practices.

In addition, the research provided evidence that using advanced digital technologies like BI and BDA can improve the performance and competitiveness of the semiconductor packaging sector. It also highlighted the essential role of digital literacy and industry-academic collaboration.

Thus, this thesis highlights the importance of collaboration between academic institutions and the industry in creating a skilled workforce for the semiconductor industry. While partnerships with universities can help create the talent needed for new technologies, more research is needed on scaling these collaborations.

6.2 Implications

The results of this thesis have important implications for both the semiconductor packaging manufacturing industry and educational institutions, especially in terms of skill development and industry growth.

1. Collaboration between Industry and Academia: As the semiconductor industry continues to become more digital and data-driven, businesses must work with academic institutions. This collaboration will help students learn how to use new technologies like BI, Big Data Analytics (BDA) and the Industrial Internet of Things (IIoT). This will help students be better prepared to meet the needs of the industry and help businesses stay competitive.

2. Skill Development: Educational programs should include the latest technologies, such as BI and BDA, to help students gain important skills like data analysis and process optimization to focus on the growing Electronics and Semiconductor manufacturing industry. These skills are important for making decisions and improving efficiency in semiconductor packaging. Exposing students to use data to solve real-world manufacturing problems will make them more valuable to industry.

3. Developing a Skilled Workforce: By collaborating with universities, the semiconductor industry can ensure a steady flow of skilled workers with the technical

knowledge and BI skills needed. This partnership will help businesses save time and money on training new hires, as graduates will already have the necessary skills to contribute to the company's operations immediately.

4. Research and Innovation: Academic institutions and businesses can work together especially in process optimisation and predictive maintenance. These collaborations in R&D can help develop new technologies and innovations that will keep the industry at the cutting edge of advancements.

5. Internships and Practical Experience: Internships are a practical approach whereby students gain hands-on experience and understand how BI tools are used in the semiconductor industry. These programs also provide businesses access to students already familiar with their industry tools and technologies. This makes it easier for companies to integrate interns into their teams quickly, while students gain valuable real-world experience and are ready for jobs.

6. Customised Training Programs: Organisations can work with research centers and training centers to create customised training programs for internal training of their employees, helping them learn the specific tools and technologies needed in semiconductor packaging. These programs can make the learning curve quicker for employees to use related advanced tools for data collection, reporting and decision-making, essential for improving efficiency and product quality.

6.3 Recommendations for Future Research

The evidence is mixed concerning the transferability of skills, therefore, the usefulness of expert skill sets with instructions is required. A limitation of this paper is that it does not consider other factors such as the challenges of technology and current geopolitical situations. A subjective analysis carried out only by the author and the absence of industry experts' validation were limitations of this paper. Clearly additional research is needed.

The research was limited to the semiconductor packaging line of manufacturing. There are other areas such as wafer level fabrication, designing, technology, infrastructure and resource availability and its allocation.

This study focused on how Business Intelligence (BI), Big Data Analytics (BDA) and the Industrial Internet of Things (IIoT) can improve the semiconductor packaging industry. While the research highlights the benefits of these technologies in boosting operational efficiency and decision-making, future research needs to look at whether these skills and technologies can be transferred to other areas of manufacturing, such as wafer-level fabrication or chip design. For example, while the study looked closely at the backend of semiconductor packaging, there's potential for BI and BDA to improve efficiency in other semiconductor processes, but more research is needed to explore this.

One limitation of this study was that it didn't take into account other factors such as geopolitical challenges or the current state of technology. For example, the global semiconductor shortage, which has impacted production worldwide, could influence how companies adopt digital tools. Future research should look at how external challenges, like global supply chain disruptions or changing international trade policies, can affect the use of AI, BI and other technologies in semiconductor manufacturing.

The study also found that the adoption of digital tools like BI can improve operational efficiency, but it doesn't fully address the specific needs of high-tech industries like semiconductor packaging. More research is needed to understand how these technologies can be customised for specific industries. While general manufacturing industries may benefit from data analytics, high-tech sectors may need more specialized solutions. Future research could investigate how different technologies can be used to meet the specific demands of sectors like semiconductor manufacturing.

Finally, this research emphasises the importance of collaboration between academic institutions and industry, especially in training skilled workers for the semiconductor industry in India. The study showed that industry partnerships with universities can help create a skilled workforce ready to adopt new technologies. However, additional research is definitely needed to explore how these partnerships can be scaled up to meet the growing industrial demand in developing countries like India.

6.4 Conclusion

This study has shown that combining Business Intelligence (BI), Big Data Analytics (BDA) and skill development is important in shaping smart manufacturing practices in the semiconductor packaging industry. By using real-time data to monitor operations and support decision-making, companies can now reduce delays, improve efficiency and have their production processes more streamlined.

The research focused on how BI, BDA, and the Industrial Internet of Things (IIoT) can help companies in India improve their performance. It also looked at the gap between what students are taught in academic programs and the practical skills employers expect from them once they enter the workforce.

The findings make it clear that digital tools such as BI and BDA allow companies to monitor their operations more closely, respond more quickly to issues, and use resources more effectively. This has led to faster production times and higher output, especially when IIoT tools are also used. These outcomes are in line with the results of earlier studies by Richardson et al. (2020), Abusweilem et al. (2019), and Rauch et al. (2019), which also found that digital technologies can improve how manufacturing systems perform.

On the education side, the study found a noticeable gap between what students learn in college and the skills they actually need on the job. While there are efforts to bridge this gap such as short-term training and partnerships between universities and companies there is still more work to be done. Researchers like Guzman et al. (2020) and Kalsoom et al. (2020) have also stressed the need to update course content and give students more hands-on experience with modern tools.

Technology alone is not enough. A well-trained workforce is equally important. This reflects the views of Moshiri et al. (2020) and Jwo et al. (2021), who also pointed out that better training, updated learning materials, and stronger ties between colleges and industries are necessary for future success.

The results of this research also support the ideas of Verma et al. (2019), who highlighted how BI helps improve decision-making, and Chenoy et al. (2019), who pointed out the growing importance of teaching skills like AI and data analytics. These are the areas where most of today's workforce needs more development.

Another key finding is that the use of automation and analytics has led to better decision-making and more reliable production by improving product quality and reduced errors. At the same time, regular training and skill-building have become more important than ever to help workers keep up with rapid changes in technology. Alharbi (2022) also noted that having both the right technology and skilled people is essential for smart manufacturing to succeed.

In summary, the future of smart manufacturing in the semiconductor packaging sector depends not just on adopting new technologies, but also on preparing people to use them well. For companies to fully benefit from these tools, colleges and industry leaders need to work together to close the skills gap. When this happens, businesses will be able to improve efficiency, ensure quality, and make better decisions. In the long run, those who invest in both modern technology and people's skills will be in a stronger position to face industry challenges and stay competitive.

APPENDIX A

SURVEY COVER LETTER

I Survey Form from the Academia

The survey was conducted covering the academic institutions to know of their level of understanding of the subject, how well they understand and how well they prepare students for the upcoming industry.

Survey Form for Academia	
Sr No	Questions
1	Does the Institute offer courses related to semiconductor manufacturing?
	Yes ☐
	No ☐
2	What level of semiconductor education does the Institute provide?
	Undergraduate Programs ☐
	Graduate Programs ☐
	Certificate Programs ☐
	Industry Training ☐
	Research Opportunities ☐
3	Does the Institute have a dedicated semiconductor lab or facility for hands-on learning?
	Yes ☐
	No ☐
4	Which courses related to semiconductor manufacturing processes are offered by the Institute?

	Introduction to Semiconductor Physics	☐
	Semiconductor Fabrication and Process Engineering	☐
	Advanced Materials for Semiconductor Devices	☐
	VLSI Design and Manufacturing	☐
	Semiconductor Nanotechnology	☐
	Packaging and Assembly of Semiconductor Devices	☐
	Other (Please specify): ___________________________	
5	How would you rate the relevance of the courses offered to current industry trends in semiconductor manufacturing?	
	Very Relevant	☐
	Somewhat Relevant	☐
	Neutral	☐
	Somewhat Irrelevant	☐
	Very Irrelevant	☐
6	Are the courses taught by qualified faculty with semiconductor industry experience?	
	Yes	☐
	No	☐
	Not Sure	☐
7	What improvements would you recommend in the curriculum for semiconductor-related courses?	

	More Hands-on/Practical Training	☐
	Inclusion of Advanced Semiconductor Manufacturing Topics	☐
	Focus on Industry-Relevant Tools and Software	☐
	Updates on Recent Technological Advances	☐
	Other (Please specify): ____________________________	
8	Does the Institute offer specialized training programs for professionals in semiconductor manufacturing?	
	Yes	☐
	No	☐
9	What type of training programs does the Institute provide?	
	Short-Term Professional Development Courses	☐
	Certification Programs	☐
	In-Depth Technical Training Workshops	☐
	On-the-Job Training Opportunities	☐
	Online Courses and Webinars	☐
	Other (Please specify): ____________________________	
10	Does the institute have tie up with industries for apprenticeship?	
	Yes	☐
	No	☐
11	What additional training programs would you suggest for the Institute to offer?	
	Semiconductor Process Integration	☐
		☐

	Equipment Maintenance and Troubleshooting	☐
	Quality Control and Testing in Semiconductor Manufacturing	☐
	Emerging Semiconductor Technologies (e.g., 3D ICs, Quantum Computing)	
	Other (Please specify): ______________________________	
12	How does Institute support students learning program to be industry ready?	
	Workshop	☐
	R&D Labs	☐
	Industry Visit	☐
	Training courses	☐
13	Does the Institute regularly organize seminars and workshops related to semiconductor technologies?	
	Yes	☐
	No	☐
14	What topics have been covered in the Institute's seminars and workshops?	
	Semiconductor Manufacturing Innovations	☐
	Advanced Materials for Semiconductor Devices	☐
	AI and Automation in Semiconductor Manufacturing	☐
	Industry Trends and Future Technologies	☐
	Semiconductor Packaging and Testing	☐
	Other (Please specify): ______________________________	
15	What topics should the Institute cover in future seminars or workshops?	
	Semiconductor Process Scaling and Efficiency	☐

	☐ Industry Collaborations in Semiconductor Research ☐ Emerging Materials for Next-Generation Semiconductors ☐ Automation and Artificial Intelligence in Manufacturing Other (Please specify): ____________________________
16	Does the Institute offer faculty development programs to enhance their expertise in semiconductor technologies?
	☐ Yes ☐ No
17	What areas should the Institute focus on to improve faculty development in semiconductor education?
	☐ Hands-on Laboratory Training ☐ Industry Collaboration and Exposure ☐ Research in Semiconductor Innovation ☐ Integration of Cutting-Edge Semiconductor Technologies into the Curriculum Other (Please specify): ____________________________
18	How would you rate the Institute's infrastructure and facilities for semiconductor education and research?
	☐ Excellent ☐ Good ☐ Satisfactory ☐ Needs Improvement ☐ Poor

20	Are there opportunities for student-led lessons or is every lesson dictated by the district's curriculum and teacher-led?
	District curriculum ☐ Teacher led ☐ National Level ☐
21	What are the Institute's strengths in semiconductor education and training?
	Strong Industry Partnerships ☐ Highly Qualified Faculty ☐ Cutting-Edge Laboratory Facilities ☐ Relevant and Up-to-Date Curriculum ☐ Other (Please specify): ____________________________
22	What are the areas in which the Institute could improve?
	Course Offerings and Curriculum ☐ Faculty Development ☐ Industry Collaboration ☐ Research Opportunities ☐ Training Programs and Workshops ☐ Other (Please specify): ____________________________
23	Any additional comments or recommendations for the Institute?
	Please provide your feedback: ____________________________

II Survey Form from the Industry

Survey was conducted covering the R&D, Government, production, corporates, consultants, industry to know their level of understanding the smart manufacturing use of IIOT advantage and their workforce on Semiconductor packaging

Survey Form from the Industry		
Sr No	**Questions**	
1	**How does your organization select its workforce? (Check all that apply)**	
	Traditional recruitment (advertisements, job boards)	☐
	Employee referrals	☐
	Talent acquisition through recruitment agencies	☐
	Social media recruitment (LinkedIn, Facebook, etc.)	☐
	Campus recruiting (universities, colleges)	☐
	Online job platforms (Indeed, Glassdoor, etc.)	☐
	Other (please specify): ________________	
2	**What key qualities do you look for when selecting a workforce?**	
	Technical skills and expertise	☐
	Problem-solving and critical thinking	☐
	Adaptability to new technologies	☐
	Communication skills	☐
	Experience in automation/AI/ML technologies	☐
	Teamwork and collaboration	☐

	Other (please specify): ________________
3	**What is the typical educational qualification required for your hires?**
	High school diploma ☐
	Bachelor's degree ☐
	Master's degree ☐
	PhD ☐
	No specific requirement ☐
4	**What field of study is preferred for your new hires?** (Select all that apply)
	Engineering ☐
	Non - Technical degree ☐
	Data Science/AI/ML ☐
	Other: ________________
5	**Skill Gap Availability Vs Requirement**
	Fresher ☐
	Apprentice trained ☐
	experience same field ☐
	expertise with related field ☐
6	**What level of semiconductor education do you prefer while hiring**
	Undergraduate Programs ☐
	Graduate Programs ☐

	Certificate Programs ☐
	Industry Training ☐
	Research Opportunities ☐
7	**Which courses related to semiconductor manufacturing processes are considered as an advantage while hiring .**
	Introduction to Semiconductor Physics ☐
	Semiconductor Fabrication and Process Engineering ☐
	Advanced Materials for Semiconductor Devices ☐
	VLSI Design and Manufacturing ☐
	Semiconductor Nanotechnology ☐
	Packaging and Assembly of Semiconductor Devices ☐
	Other (Please specify): ____________________________
8	**Which technologies are currently used in your manufacturing processes?** (Select all that apply)
	Robotics/Automation ☐
	AI/ML ☐
	IoT(Internet of Things) ☐
	Other: ________________
9	**How have AI, ML and Automation benefited your business?** (Select all that apply)
	Increased efficiency ☐
	Cost reduction ☐
	☐

	Quality improvement	☐
	Predictive maintenance	
	Other: ________________	
10	**How important is technology (AI/ML/Automation) to your future growth?**	
	Very important	☐
	Moderately important	☐
	Not important	☐
11	**Does your organization provide training for AI, ML, or Automation technologies?**	
	Yes, comprehensive training	☐
	Yes, on a need basis	☐
	No training	☐
12	**What training methods are used?** (Select all that apply)	
	In-house sessions	☐
	Online courses	☐
	Workshops/seminars	☐
	Peer mentoring	☐
	Other: ________________	
13	**What key skills are trained for these technologies?**	
	Programming	☐
	Machine learning algorithms	☐
		☐

	Automation systems ☐
	Data analysis
	Other: ________________
14	**Orientation Training at the time of Joining**
	☐ 2 weeks
	☐ 2-4 Weeks
	☐ 90 Days
15	**Reorientation training on completion after**
	☐ 1 year
	☐ 2 year
	Other: ________________
16	**What degrees or certifications are most beneficial for employees working with AI, ML, or Automation?** (Select all that apply)
	☐ Bachelor's in Computer Science, Engineering, or Data Science
	☐ Master's in AI/ML or Robotics
	☐ Certification in AI/ML (e.g., Google AI, Microsoft)
	☐ Certification in Automation (e.g., PLC, Robotics)
	Other: ________________
17	**How do you assess the viability of AI, ML, or Automation in your business?**
	☐ Cost-benefit analysis
	☐ Productivity gains
	☐

	Competitive advantage
	Other: ________________
18	**What areas are you planning to automate in the next 1-3 years?** (Select all that apply)
	Production/assembly ☐
	Maintenance ☐
	Supply chain ☐
	Quality control ☐
	Other: ________________
19	**What is the biggest challenge in adopting AI, ML, or Automation?**
	High costs ☐
	Lack of skilled workforce ☐
	Integration with existing systems ☐
	Other: ________________

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