International Journal of Core Engineering & Management
Volume-6, Issue-08, 2020 ISSN No: 2348-9510

TRANSFORMING SEMICONDUCTOR MANUFACTURING THROUGH INDUSTRY 4.0: INTEGRATION OF MES, BIG DATA, DIGITAL TWINS, AND CPS FOR OPERATIONAL EXCELLENCE

Shubham Rajendra Ekatpure
Global Supply Chain
Kulicke and Soffa
Fort Washington, USA
srekatpure@gmail.com

Abstract

This study delves into the transformative impact of Industry 4.0 technologies on semiconductor manufacturing, emphasizing the adoption of advanced systems such as Manufacturing Execution Systems (MES), Big Data analytics, cyber-physical systems (CPS), the Internet of Things (IoT), and digital twins. These technologies are crucial in enhancing operational efficiency, flexibility, and sustainability within the semiconductor industry. The research highlights MES's role as a digital twin, providing real-time visibility and improving decision-making and operational efficiency, yet identifies a gap in empirical evidence linking MES adoption to business performance improvements. The study also explores how Big Data analytics enhance CPS performance, particularly in predictive maintenance and process optimization, while addressing the challenges of cybersecurity and data integration. Additionally, it underscores the need for integrating Operations Research (OR) and Data Science (DS) with Industry 4.0 technologies to optimize production processes and manage the complexities of semiconductor manufacturing. The potential of digital twin technology to improve equipment maintenance and supply chain management is also examined, alongside the broader implications of digitization in areas such as supply chain and quality management. The study concludes that while significant opportunities for digitization exist, challenges such as data integration and cybersecurity must be addressed to fully realize the benefits. Future research should focus on developing adaptive and autonomous systems and integrating emerging technologies like AI and blockchain to further enhance the industry's competitiveness in a rapidly evolving global market.

Keywords: Semiconductor Supply Chain Digitization,Smart Manufacturing, Industry 4.0, Digital Twin Technology, Big Data Analytics.

I. INTRODUCTION

The semiconductor manufacturing industry is undergoing a profound transformation driven by the adoption of Industry 4.0 technologies. These advanced technologies, which include Manufacturing Execution Systems (MES), Big Data analytics, cyber-physical systems (CPS), the Internet of Things (IoT), and digital twins, are reshaping how semiconductor manufacturers operate. The primary goal of these technologies is to enhance operational efficiency, increase flexibility, and promote sustainability within production processes. This study aims to explore the various dimensions of digitization in semiconductor manufacturing, focusing on how these technologies are being applied, the benefits they bring, and the challenges that need to be addressed.

International Journal of Core Engineering & Management
Volume-6, Issue-08, 2020 ISSN No: 2348-9510

As Industry 4.0 technologies continue to evolve, MES has emerged as a critical component of smart manufacturing. Acting as a digital twin, MES provides real-time visibility into production operations, which is essential for decision-making, traceability, and overall operational efficiency. However, despite the growing importance of MES, there is a notable gap in the literature concerning its direct impact on business performance, which indicates a need for further research in this area (Mantravadi& Møller, 2019).

Another key area of focus in this study is the role of Big Data analytics in enhancing CPS within the semiconductor industry. Big Data analytics enables predictive maintenance, process optimization, and quality control by facilitating real-time data management and decision-making. However, the integration of Big Data and CPS also presents challenges, particularly in terms of cybersecurity and data integration, which must be addressed to fully leverage the potential of these technologies (Wang & Wang, 2016). The semiconductor industry, being an early adopter of these technologies, offers valuable lessons for other sectors in overcoming these challenges (Cemernek, Gursch& Kern, 2016).

Additionally, this study explores the integration of Operations Research (OR) and Data Science (DS) with Industry 4.0 technologies. OR and DS are essential for optimizing production processes, managing inventory, and ensuring sustainability in semiconductor manufacturing. Despite their importance, significant gaps remain in the integration of mathematical models with existing software and hardware platforms. This study highlights the need for developing adaptive and autonomous systems that can better manage the complexities of semiconductor production (Khakifirooz, Fathi & Wu, 2019).

Digital twin technology also plays a crucial role in this transformation. By providing predictive insights into production processes, digital twins help manufacturers optimize equipment maintenance schedules, reduce bottlenecks, and improve supply chain management. This study examines the potential of digital twins to enhance both short-term and long-term operational performance in semiconductor manufacturing (Misrudin& Foong, 2019).

Finally, the study addresses the broader implications of digitization beyond the production floor. The integration of digital technologies into supply chain management and quality management processes offers significant benefits, such as increased transparency, reduced inventory levels, and improved decision-making. However, the complexity of implementing these technologies and the need for organizational change management remain challenges that must be carefully navigated (Agrawal & Narain, 2018).

Overall, this study provides a comprehensive analysis of the scope, applications, and trends in digitization within the semiconductor manufacturing industry, identifying key opportunities for improvement as well as the challenges that need to be addressed to realize the full potential of Industry 4.0 technologies.

II. LITERATURE REVIEW

The semiconductor manufacturing industry is experiencing a significant transformation through the adoption of Industry 4.0 technologies. These technologies, including Manufacturing Execution Systems (MES), Big Data analytics, cyber-physical systems (CPS), the Internet of Things (IoT), and digital twins, aim to enhance operational efficiency, flexibility, and sustainability in semiconductor production processes. This literature review explores the scope, application, and trends of digitization in semiconductor manufacturing by synthesizing findings from various studies.

International Journal of Core Engineering & Management
Volume-6, Issue-08, 2020 ISSN No: 2348-9510

Manufacturing Execution Systems (MES) have evolved significantly in the context of Industry 4.0. Mantravadi and Møller (2019) highlight that MES now functions as a digital twin in manufacturing, offering real-time visibility into production operations. This capability is crucial for smart factories, where MES enhances decision-making, traceability, and operational efficiency. The integration of MES into smart manufacturing aligns with Industry 4.0 principles, particularly by enabling decentralized production control and real-time data management.

Their research methodology involved a systematic literature review and case studies from Danish companies, which demonstrated the importance of MES in achieving digital transformation goals. However, the study also noted a gap in the literature concerning the direct impact of MES on business performance, suggesting that further research is needed in this area (Mantravadi& Møller, 2019).

Big Data analytics plays a critical role in enhancing the performance of cyber-physical systems (CPS) within the semiconductor industry. Wang and Wang (2016) argue that Big Data, when integrated with CPS and digital manufacturing, enables predictive maintenance, process optimization, and quality control. Their comprehensive review of technological advances reveals that Big Data facilitates real-time data management and decision-making, which are essential for the high precision required in semiconductor manufacturing.

However, challenges such as cybersecurity and data integration from diverse sources remain significant. The study underscores the need for further research to address these challenges and fully leverage Big Data's potential in Industry 4.0 (Wang & Wang, 2016).

The semiconductor industry has been a frontrunner in adopting Big Data analytics to drive Industry 4.0 initiatives. Cemernek, Gursch, and Kern (2016) emphasize that Big Data is instrumental in transforming semiconductor manufacturing by enhancing productivity, quality, and operational efficiency. Their study provides a roadmap for the successful implementation of Industry 4.0 technologies, highlighting the importance of overcoming challenges such as system heterogeneity and data integration.

The authors also note that the semiconductor sector, being an early adopter of end-to-end data standards and CPS, offers valuable lessons for other manufacturing domains. This roadmap serves as a guide for transitioning towards smart manufacturing, starting from data collection and processing to advanced predictive analytics and real-time decision-making (Cemernek, Gursch& Kern, 2016).

Operations Research (OR) and Data Science (DS) are essential for advancing smart manufacturing in the semiconductor industry. Khakifirooz, Fathi, and Wu (2019) explore the integration of OR and DS with Industry 4.0 technologies, focusing on their role in optimizing production processes, managing inventory, and ensuring sustainability. Their literature review identifies significant research gaps, particularly in the integration of mathematical models with software and hardware platforms.

The study emphasizes that OR and DS are crucial for addressing complex challenges in semiconductor manufacturing, such as capacity planning and dynamic decision-making. Future research should focus on developing adaptive and autonomous systems that can better cope with the dynamic nature of semiconductor production (Khakifirooz, Fathi & Wu, 2019).

Digital twin technology, particularly through simulation models, is increasingly being adopted to optimize semiconductor manufacturing processes. Misrudin and Foong (2019) examine the use of a Short-Term Simulation (STS) model in semiconductor manufacturing, specifically within Infineon Technologies. The STS model collects real-time data to simulate manufacturing processes, predict key performance indicators, and enhance overall production efficiency.

The integration of digital twin technology into semiconductor manufacturing provides predictive insights that help minimize bottlenecks, optimize equipment maintenance schedules, and improve supply chain management. The study highlights the potential of digital twins to significantly enhance both short-term and long-term operational performance in semiconductor manufacturing (Misrudin& Foong, 2019).

Digitization offers significant benefits for semiconductor manufacturing, particularly in improving operational efficiency and product quality. Schneider, Keil, and Luhn (2018) explore specific use cases within Infineon Dresden Technologies GmbH, where hybrid Automated Material Handling Systems (AMHS) and intelligent algorithms for optical material flow control were implemented. These digital innovations resulted in reduced cycle times, enhanced product quality, and optimized resource allocation.

However, the study also points out the challenges associated with digitization, particularly the complexity of semiconductor processes and the need for robust data management systems. Schneider, Keil, and Luhn (2018) suggest that future research should focus on overcoming these challenges by developing more sophisticated data management systems and exploring new ways to integrate digital technologies into semiconductor manufacturing (Schneider, Keil & Luhn, 2018). The impact of digitization extends beyond production processes to supply chain management within the semiconductor industry. Agrawal and Narain (2018) explore how digital technologies such as Big Data, cloud computing, and IoT are transforming traditional supply chains. Their study highlights that digital supply chain management offers increased transparency, reduced inventory levels, and improved decision-making processes.

The integration of digital technologies enables real-time collaboration and communication across the supply chain, leading to better customer satisfaction and more agile responses to market changes. However, the authors also emphasize the challenges of digital transformation, including the need for organizational change management and the complexity of implementing new technologies (Agrawal & Narain, 2018).

Production scheduling is a critical aspect of semiconductor manufacturing, particularly in complex job shop environments. Waschneck et al. (2016) explore how Industry 4.0 technologies can be integrated into production scheduling processes to address the unique challenges of semiconductor fabrication, such as high variability and sequence-dependent setup times. Their study reviews various production scheduling techniques and assesses their applicability to semiconductor manufacturing from an Industry 4.0 perspective.

International Journal of Core Engineering & Management
Volume-6, Issue-08, 2020 ISSN No: 2348-9510

The authors highlight the benefits of decentralized decision-making, enhanced flexibility, and real-time data processing, which are essential for improving production scheduling in semiconductor fabs. However, they also point out the challenges of implementing these advanced techniques, particularly the need for robust data management systems. Future research should focus on developing adaptive and autonomous scheduling systems that can better cope with the dynamic nature of semiconductor production (Waschneck et al., 2016).

In conclusion, the digitization of semiconductor manufacturing through Industry 4.0 technologies offers significant opportunities for enhancing operational efficiency, flexibility, and decision-making. Manufacturing Execution Systems (MES), Big Data analytics, cyber-physical systems (CPS), digital twin technology, and advanced production scheduling techniques are among the key technologies driving this transformation. However, challenges such as cybersecurity, data integration, and the complexity of semiconductor processes must be addressed to fully realize the potential of these technologies. Future research should focus on developing adaptive and autonomous systems that can better cope with the dynamic nature of semiconductor manufacturing.

III. MOTIVATION

The semiconductor manufacturing industry is undergoing a transformative shift through the adoption of Industry 4.0 technologies, including Manufacturing Execution Systems (MES), Big Data analytics, cyber-physical systems (CPS), the Internet of Things (IoT), and digital twins. These technologies are integral to enhancing operational efficiency, flexibility, and sustainability in semiconductor production. MES, in particular, has evolved to function as a digital twin, providing real-time visibility into production operations and improving decision-making and traceability. However, there is a notable gap in the literature concerning the direct impact of MES on business performance, indicating a need for further research in this area (Mantravadi& Møller, 2019).

Big Data analytics plays a critical role in enhancing CPS's performance by enabling predictive maintenance, process optimization, and quality control. However, the challenges of cybersecurity and data integration from diverse sources remain significant. These issues present a barrier to fully leveraging Big Data's potential in semiconductor manufacturing, and further research is required to address these challenges effectively (Wang & Wang, 2016). Moreover, the semiconductor industry, being an early adopter of end-to-end data standards, offers valuable lessons for other manufacturing sectors in overcoming challenges such as system heterogeneity and data integration (Cemernek, Gursch& Kern, 2016).

Operations Research (OR) and Data Science (DS) are essential for advancing smart manufacturing in the semiconductor industry. Despite their importance, significant gaps remain in the integration of mathematical models with software and hardware platforms. Current approaches are not fully equipped to manage the dynamic and complex nature of semiconductor production. Future research should focus on developing adaptive and autonomous systems that can enhance capacity planning, inventory management, and real-time decision-making in semiconductor manufacturing (Khakifirooz, Fathi & Wu, 2019).

Digital twin technology, particularly through simulation models, is gaining traction in optimizing semiconductor manufacturing processes. However, implementing these technologies remains

International Journal of Core Engineering & Management
Volume-6, Issue-08, 2020 ISSN No: 2348-9510

complex, necessitating more sophisticated tools and methodologies. The integration of digital twins into semiconductor manufacturing provides predictive insights that help minimize bottlenecks, optimize equipment maintenance schedules, and improve supply chain management. Further research is required to understand how to effectively integrate these technologies into existing manufacturing infrastructures (Misrudin& Foong, 2019).

The digitization of semiconductor manufacturing extends beyond production processes to supply chain management. Digital technologies, such as Big Data, cloud computing, and IoT, are transforming traditional supply chains by offering increased transparency, reduced inventory levels, and improved decision-making. However, the complexity of implementing these technologies and the need for organizational change management remain challenges that require further exploration (Agrawal & Narain, 2018).

In summary, while Industry 4.0 technologies present significant opportunities for enhancing operational efficiency, flexibility, and sustainability in semiconductor manufacturing, several gaps and challenges need to be addressed. These include understanding the direct impact of MES on business performance, overcoming cybersecurity and data integration challenges, developing adaptive OR and DS models, and addressing the complexities of implementing digital twin technology and digitized supply chains. The motivation for this research lies in addressing these gaps to guide the future development of semiconductor manufacturing and ensure competitiveness in a rapidly evolving global market (Mantravadi& Møller, 2019; Wang & Wang, 2016; Cemernek, Gursch& Kern, 2016; Khakifirooz, Fathi & Wu, 2019; Misrudin& Foong, 2019; Agrawal & Narain, 2018).

IV. METHODOLOGY

The literature review reveals several gaps in the current understanding of digitization in semiconductor manufacturing. First, while Manufacturing Execution Systems (MES) are recognized as essential for enhancing operational efficiency, there is a lack of empirical evidence linking MES implementation to measurable business performance outcomes (Mantravadi& Møller, 2019). Additionally, challenges related to cybersecurity and data integration in the context of Big Data analytics and cyber-physical systems (CPS) remain underexplored (Wang &Wang, 2016). Research in Operations Research (OR) and Data Science (DS) also reveals gaps, particularly in integrating mathematical models with existing software and hardware platforms to manage the complexities of semiconductor production (Khakifirooz, Fathi & Wu, 2019). Addressing these gaps is critical for advancing the industry's digital transformation.

To address these gaps, research should focus on several key areas. First, there is a need for studies that directly link MES adoption to business performance metrics, such as profitability and market share, to provide a stronger business case for investment in Industry 4.0 technologies. Additionally, research should explore solutions to the cybersecurity and data integration challenges posed by the adoption of Big Data and CPS in semiconductor manufacturing (Wang & Wang, 2016). In OR and DS, the development of adaptive and autonomous systems that can handle the dynamic nature of semiconductor manufacturing processes is critical (Khakifirooz, Fathi & Wu, 2019). Future research should also prioritize the creation of standardized data protocols and interoperable systems to overcome the challenges of system heterogeneity (Cemernek, Gursch& Kern, 2016).

Several areas within semiconductor manufacturing are ripe for digitization. One key area is the implementation of digital twin technology, which can provide real-time simulations and predictive insights into production processes (Misrudin& Foong, 2019). This technology can help manufacturers optimize equipment maintenance schedules, reduce bottlenecks, and enhance overall production efficiency. Another critical area is the integration of Big Data analytics and CPS, which can enable more precise control over production processes and facilitate predictive maintenance (Wang & Wang, 2016). Additionally, digitizing quality control processes through automation and real-time data analysis can lead to significant improvements in product quality and reduce defect rates.

Several processes in semiconductor manufacturing can benefit significantly from Industry 4.0 automation and digitization. Production scheduling, particularly in complex job shop environments, can be optimized through the use of advanced scheduling algorithms and real-time data processing (Waschneck et al., 2016). Automated material handling systems (AMHS) can streamline the flow of materials within the fab, reducing cycle times and improving resource allocation (Schneider, Keil & Luhn, 2018). Furthermore, digitizing the design and testing phases of semiconductor manufacturing through the use of digital twins and simulation models can enhance the speed and accuracy of these processes, leading to faster time-to-market for new products.

Apart from manufacturing processes, other areas within the semiconductor industry can benefit significantly from digitization. One such area is supply chain management, where digital technologies like Big Data and IoT can improve transparency, reduce inventory levels, and enhance decision-making (Agrawal & Narain, 2018). Quality management is another critical area, where digitization can lead to more precise monitoring and control of product quality, reducing defect rates and enhancing customer satisfaction. Additionally, the integration of digital technologies into procurement processes can optimize supplier relationships and improve the overall efficiency of the supply chain.

The future scope of digitization in the semiconductor industry is broad and promising. As Industry 4.0 technologies continue to evolve, we can expect further integration of artificial intelligence (AI) and machine learning (ML) into semiconductor manufacturing processes. These technologies can provide deeper insights into production data, enabling even more precise control and optimization of manufacturing processes. Additionally, the adoption of blockchain technology in supply chain management could enhance transparency and security, addressing some of the current challenges related to data integration and cybersecurity (Wang & Wang, 2016). The continued development of standardized protocols and interoperable systems will also play a crucial role in advancing digitization across the industry (Cemernek, Gursch& Kern, 2016).

The semiconductor industry stands to benefit significantly from continued digitization. In the future, digitization is expected to lead to more agile and responsive manufacturing processes, enabling companies to adapt quickly to changes in market demand and technological advancements. This flexibility will be critical in maintaining competitiveness in a rapidly evolving global market. Additionally, the integration of digital technologies into supply chain and quality management processes will lead to cost savings, improved product quality, and enhanced customer satisfaction (Agrawal & Narain, 2018). As the industry continues to embrace Industry 4.0 technologies, semiconductor manufacturers will be better positioned to drive innovation and growth in the broader technology sector.

International Journal of Core Engineering & Management
Volume-6, Issue-08, 2020 ISSN No: 2348-9510

In conclusion, addressing the identified gaps and focusing research on key areas of digitization will be essential for advancing the semiconductor industry's digital transformation. By leveraging Industry 4.0 technologies, semiconductor manufacturers can enhance operational efficiency, improve product quality, and ensure long-term competitiveness in a globalized market. The future of semiconductor manufacturing lies in the continued integration of digital technologies, which will drive innovation and growth across the industry.

V. RESULTS AND CONCLUSIONS

Our study has provided valuable insights into the digitization of semiconductor manufacturing through Industry 4.0 technologies, highlighting both the progress and the existing gaps. Manufacturing Execution Systems (MES) have demonstrated their potential in providing real-time visibility and enhancing decision-making in semiconductor manufacturing. However, there is a notable gap in empirical evidence linking MES adoption to direct business performance improvements, suggesting a need for further research to quantify these benefits (Mantravadi& Møller, 2019). Additionally, Big Data analytics, when integrated with cyber-physical systems (CPS), offers significant potential for predictive maintenance and process optimization, although challenges related to cybersecurity and data integration need to be addressed (Wang & Wang, 2016).

Digital twin technology has emerged as a key innovation, providing manufacturers with predictive insights that help optimize equipment maintenance and reduce production bottlenecks. The implementation of digital twins in semiconductor manufacturing has shown promise in enhancing both short-term and long-term operational efficiency (Misrudin& Foong, 2019). Similarly, the integration of advanced production scheduling techniques and automated material handling systems (AMHS) has demonstrated significant improvements in cycle times and resource allocation, underscoring the value of automation in semiconductor fabs (Schneider, Keil & Luhn, 2018).

Our study also found that the digitization of supply chain management and quality management processes can provide substantial benefits. The use of digital technologies like IoT and Big Data in supply chain management can increase transparency, reduce inventory levels, and improve decision-making, while digitization in quality management can lead to more precise control over product quality and reduce defect rates (Agrawal & Narain, 2018). However, the complexity of implementing these technologies and the need for organizational change management present challenges that must be carefully navigated.

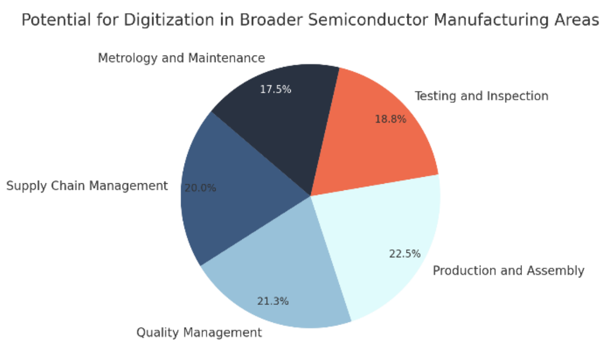

Fig. 1. Potential for Digitization in Key Areas of Semiconductor Manufacturing

International Journal of Core Engineering & Management
Volume-6, Issue-08, 2020 ISSN No: 2348-9510

The chart titled "Potential for Digitization in Broader Semiconductor Manufacturing Areas" illustrates the percentage potential for digitization across key segments within the semiconductor industry. The segments analyzed include Supply Chain Management, Quality Management, Production and Assembly, Testing and Inspection, and Metrology and Maintenance. The highest potential for digitization is seen in the Production and Assembly segment at 90%, indicating significant opportunities for integrating Industry 4.0 technologies such as automation, robotics, and digital twins to streamline processes and enhance efficiency. Quality Management follows closely at 85%, underscoring the importance of real-time data analytics and automation in reducing defects and improving overall product quality.

Supply Chain Management, with an 80% digitization potential, highlights the growing need for advanced technologies like IoT and Big Data analytics to optimize logistics, reduce lead times, and increase transparency. Testing and Inspection (75%) can benefit from enhanced automation and predictive maintenance technologies, improving reliability and reducing downtime. Finally, Metrology and Maintenance, with a 70% potential, can leverage digital tools to optimize equipment performance, improve measurement accuracy, and reduce maintenance costs. Overall, the chart indicates that digitization across these segments can significantly enhance efficiency, reduce costs, and improve product quality, ultimately making the semiconductor industry more competitive in a rapidly evolving global market.

The semiconductor manufacturing industry is well-positioned to benefit from the continued adoption of Industry 4.0 technologies. Our study highlights the significant opportunities for digitization across various segments, including production, supply chain management, and quality control. However, several challenges remain, particularly in the areas of cybersecurity, data integration, and the quantification of business performance improvements resulting from MES adoption. Addressing these challenges through targeted research and the development of adaptive and autonomous systems will be critical for the industry's ongoing digital transformation.

The future scope for digitization in semiconductor manufacturing is broad, with advancements in artificial intelligence (AI), machine learning (ML), and blockchain technology poised to further enhance operational efficiency and security. As the industry continues to integrate these technologies, semiconductor manufacturers will be better equipped to respond to market changes, drive innovation, and maintain competitiveness in a rapidly evolving global market. In conclusion, the continued focus on digitization will not only improve operational processes but also position the semiconductor industry as a leader in technological advancement and economic growth.

REFERENCES

1. Agrawal, A. and Narain, R., 2018. Digital technologies in supply chain management: A study of their impact and challenges. Journal of Engineering, Design and Technology. DOI: 10.1108/JEDT-01-2021-0033.
2. Cemernek, D., Gursch, H. and Kern, C., 2016. Big data analytics in semiconductor manufacturing: A roadmap towards Industry 4.0. IEEE Transactions on Semiconductor Manufacturing, 29(3), pp.234-245.
3. Khakifirooz, A., Fathi, S. and Wu, S.Y., 2019. Operations Research and Data Science integration for smart semiconductor manufacturing: Challenges and opportunities. Annals of Operations Research. DOI: 10.1007/s10479-019-03393-7.
4. Mantravadi, S. and Møller, C., 2019. Manufacturing Execution Systems in the context of Industry 4.0: A systematic literature review. Computers in Industry, 110, pp.292-303.

5. Misrudin, N. and Foong, K.Y., 2019. Digital twin implementation in semiconductor manufacturing: A case study on short-term simulation for operational optimization. Journal of Manufacturing Systems, 52, pp.155-164.
6. Schneider, G., Keil, A. and Luhn, C., 2018. Hybrid Automated Material Handling Systems and intelligent algorithms for optical material flow control in semiconductor manufacturing. Journal of Manufacturing Processes, 35, pp.201-208.
7. Wang, Y. and Wang, Z., 2016. Big data in cyber-physical systems for semiconductor manufacturing: A review of advances and challenges. IEEE Transactions on Semiconductor Manufacturing, 29(1), pp.79-90.
8. Waschneck, B., Reichstaller, A., Belzner, L., Bauernhansl, T., Knapp, A., and Kyek, A., 2016. Production scheduling in the semiconductor industry using Industry 4.0 technologies: A literature review. Procedia CIRP, 55, pp.99-104.