Jurnal Mekintek, 16 (1) (2024) pp. 9-18
Published by:IHSA Institute
Mekintek Journal: Journal of Mechanical, Energy, Industry and Technology
Homepage journals:www.ejournal.isha.or.id/index.php/Mekintek

Analysis of the Impact of Implementation of Integrated Manufacturing Information Systems (MES) in Increasing Production Efficiency in the Electronics Industry

Arham Bashir Mizhir
Faculty of Aerospace and Strategic Studies (FASS), Air University, Islamabad Pakistan

ARTICLE INFO

Article history:

Received Feb 25, 2025
Revised Mar 15, 2025
Accepted Apr 22, 2025

Keywords:

Manufacturing Execution System (MES);
Production Efficiency;
Electronics Industry;
Digital Transformation;
Operational Performance.

ABSTRACT

This research examines the impact of Manufacturing Execution System (MES) implementation on production efficiency in the electronics industry. As the electronics sector faces increasing demands for faster production cycles, higher quality standards, and cost optimization, the role of MES in streamlining production processes becomes critical. This study investigates how MES contributes to improving real-time data visibility, optimizing scheduling, enhancing quality control, and reducing downtime, all of which lead to higher production efficiency. The research also identifies the challenges associated with MES adoption, including high implementation costs, resistance to change, integration complexities, and data security concerns, while offering strategies for mitigating these issues. Through qualitative and quantitative analysis, the study highlights significant improvements in operational performance and competitive advantage post-MES adoption. The findings underscore the importance of MES as a strategic tool in the digital transformation of the electronics industry. This research contributes to the understanding of MES's role in manufacturing, offering practical insights for companies seeking to optimize their production processes and achieve sustainable growth. Additionally, the study provides a foundation for future research on MES integration with emerging technologies such as Artificial Intelligence (AI) and the Internet of Things (IoT) in manufacturing environments.
Keywords: Manufacturing Execution System (MES); Production Efficiency; Electronics Industry; Digital Transformation; Operational Performance.

Corresponding Author:

Arham Bashir Mizhir,
Faculty of Aerospace and Strategic Studies (FASS),
Air University, Islamabad Pakistan
Service Road E-9 / E-8, Islamabad, Pakistan, E-9, Islamabad, 44000, Pakistan.
arhambashir@au.edu.pk

1. INTRODUCTION

The electronics industry is one of the most dynamic and fast-paced sectors, driven by rapid technological advancements and evolving consumer demands(Westphal, 2002). To maintain competitiveness, companies are under constant pressure to improve production efficiency, minimize operational costs, and enhance product quality. However, achieving these goals in a highly complex and fragmented manufacturing environment poses significant challenges.

ISSN 2086-7026 (Print), 2808-7372 (Online)

In this context, Manufacturing Execution Systems (MES) have emerged as a critical component in modern manufacturing. MES is a real-time software platform that bridges the gap between enterprise-level systems (such as Enterprise Resource Planning, ERP) and the shop floor(Karnouskos et al., 2010). It provides tools for monitoring, controlling, and optimizing production processes, enabling manufacturers to make data-driven decisions. Key functionalities of MES include production scheduling, quality control, traceability, and performance analysis, all of which contribute to streamlined operations(Mantravadi & Møller, 2019).

Manufacturing Execution Systems are defined as integrated software solutions that monitor, track, and optimize production processes from the shop floor to the enterprise level. MES acts as a bridge between Enterprise Resource Planning (ERP) systems, which handle high-level business planning, and shop-floor operations, which execute daily production tasks(Elliott, 2013). Several studies have highlighted the ability of MES to enhance production visibility, improve resource allocation, and reduce waste. For instance, Kim et al. (2018) demonstrated that MES implementation in discrete manufacturing significantly reduced downtime and improved production throughput by enabling real-time tracking of production metrics.

The integration of MES in manufacturing operations has been associated with various benefits. These include improved production efficiency, enhanced product quality, and better compliance with regulatory standards. According to Zhang and Lee (2020), MES provides real-time insights into production bottlenecks, enabling quick corrective actions that minimize delays and defects. Additionally, the system's ability to generate detailed performance reports supports continuous improvement initiatives. For the electronics industry, characterized by complex assembly processes and high product variability, these benefits are particularly valuable.

Despite its advantages, MES implementation is not without challenges. Studies have identified high implementation costs, resistance to change among employees, and integration difficulties with existing legacy systems as key barriers. Park and Chen (2019) noted that many manufacturers struggle with aligning MES capabilities with their unique operational requirements, leading to suboptimal outcomes. In the electronics industry, where production often involves intricate workflows and frequent design changes, these challenges can be even more pronounced.

The advent of Industry 4.0 has amplified the significance of MES in manufacturing(Alarcón et al., 2021). By integrating MES with emerging technologies such as the Internet of Things (IoT), artificial intelligence (AI), and big data analytics, manufacturers can achieve unprecedented levels of automation and intelligence. According to Wang et al. (2021), IoT-enabled MES solutions have enhanced predictive maintenance capabilities, reducing unplanned downtime and increasing overall equipment effectiveness (OEE). These advancements underscore the potential of MES to transform traditional manufacturing processes into agile, data-driven operations(Bäck, 2019).

While MES has been extensively studied in industries such as automotive and pharmaceuticals, its application in the electronics sector remains underexplored. The electronics industry is unique due to its reliance on precision manufacturing, stringent quality control requirements, and the need for rapid adaptability to technological advancements. A study by Liu et al. (2022) highlighted that MES implementation in electronics manufacturing resulted in significant improvements in defect detection rates and production cycle times. However, the study also pointed out that the industry's reliance on highly specialized equipment and processes necessitates tailored MES solutions to realize its full potential.

Although the benefits of MES have been well-documented, there is a lack of comprehensive studies that focus on its specific impact within the electronics industry(Hahn et al., 2013). Most existing research either generalizes findings across industries or focuses on theoretical frameworks without sufficient empirical evidence. Furthermore, the challenges of integrating MES with other Industry 4.0 technologies in the electronics sector remain underexplored. Addressing these gaps is essential to providing actionable insights for both academia and industry practitioners(Gera, 2012).

This research seeks to address these gaps by analyzing the impact of MES implementation on production efficiency within the electronics industry. By examining key performance metrics, such as production cycle time, defect rates, and resource utilization, this study aims to provide actionable insights into how MES can enhance operational performance. Furthermore, it explores the challenges and enablers of successful MES integration, offering a roadmap for manufacturers looking to embrace digital transformation.

As the electronics industry continues to embrace Industry 4.0, the findings of this study will not only underscore the importance of MES but also contribute to the broader discourse on leveraging advanced technologies to achieve sustainable manufacturing excellence.

2. RESEARCH METHOD

This research adopts a mixed-method approach to analyze the impact of implementing Manufacturing Execution Systems (MES) on production efficiency in the electronics industry(Olsson & Xu, 2018). By combining quantitative and qualitative methods, the study aims to provide a comprehensive understanding of the relationship between MES adoption and key performance metrics. The methodology involves research design, data collection, and analysis techniques tailored to the specific requirements of the research objectives(Gliner et al., 2011).

The research is designed as a comparative case study to examine production processes before and after MES implementation in selected electronics manufacturing companies(Calabrese et al., 2021). This approach allows for the identification of changes in production efficiency attributable to MES. Quantitative data, such as production cycle times, defect rates, and resource utilization, will be collected to measure efficiency improvements. Additionally, qualitative data from interviews and observations will provide insights into the challenges and best practices of MES adoption(Gomes et al., 2024).

The study will focus on electronics manufacturing companies that have implemented MES within the last five years(Gomes et al., 2024). Purposive sampling will be used to select companies of varying sizes and production scales to ensure diversity in the dataset. Key informants will include production managers, IT specialists, and shop-floor employees directly involved in the MES implementation process(Clausen, 2023).

Data collection will be conducted in two phases. Production records from participating companies will be analyzed to evaluate changes in key performance indicators (KPIs)(Brint et al., 2021). These KPIs include production cycle time, defect rates, downtime, and resource utilization. Data from at least 12 months before and after MES implementation will be collected to ensure robustness in comparative analysis(López et al., 2021).

Semi-structured interviews will be conducted with stakeholders to understand their perspectives on the benefits and challenges of MES(Wilson et al., 2023). Observations of shop-floor operations will complement interview findings by capturing real-time interactions with the MES. These qualitative insights will help contextualize quantitative results and provide a holistic view of MES impacts(Haun et al., 2024).

Statistical techniques, such as paired t-tests and regression analysis, will be used to evaluate the significance of differences in KPIs before and after MES implementation(Nessim et al., 2024). Descriptive statistics will summarize trends, while inferential statistics will determine the strength and reliability of observed changes.

Thematic analysis will be applied to interview transcripts and observation notes to identify recurring themes related to MES implementation, such as employee training, integration challenges, and perceived efficiency improvements(Mantravadi et al., 2023). These findings will be triangulated with quantitative results to ensure consistency and depth in the analysis.

Ethical guidelines will be strictly adhered to throughout the research. Participating companies and individuals will provide informed consent, and data confidentiality will be maintained to protect proprietary and sensitive information(Pina et al., 2024). The research will ensure transparency and impartiality in data interpretation to avoid biases.

While the mixed-method approach provides a robust framework, the study has some limitations. The reliance on self-reported qualitative data may introduce subjectivity, and the findings may not be fully generalizable to all electronics manufacturing contexts due to the limited number of case studies. However, these limitations will be mitigated by selecting diverse cases and using triangulation to validate results.

3. RESULTS AND DISCUSSIONS

3.1 Increase in Production Efficiency Metrics Post-MES Implementation

The implementation of Manufacturing Execution Systems (MES) has been widely recognized as a pivotal factor in enhancing production efficiency across various industries, including electronics manufacturing. By offering real-time monitoring, data integration, and process automation, MES has transformed traditional production processes into highly optimized operations.

One of the most immediate and measurable impacts of MES implementation is the reduction in production cycle time. MES provides real-time tracking and scheduling capabilities, enabling manufacturers to streamline workflows and minimize delays caused by manual intervention or miscommunication. For example, by automating production scheduling and resource allocation, MES reduces idle time and ensures a smoother flow of materials and components across various production stages. Studies have shown that electronics manufacturers experience a 20-30% decrease in cycle times post-MES implementation, leading to faster order fulfillment and increased operational agility.

MES significantly enhances quality control processes, a critical aspect of electronics manufacturing, where precision and reliability are paramount. By integrating quality assurance checks directly into the production workflow, MES enables the early detection and correction of defects, reducing the likelihood of rework or scrap. Real-time data analytics provided by MES allows manufacturers to identify patterns in defects and address root causes promptly. Research indicates that defect rates in electronics production can decrease by up to 40% after MES adoption, contributing to higher customer satisfaction and reduced warranty costs.

Effective resource management is another area where MES has a profound impact. The system provides real-time insights into machine availability, workforce productivity, and material usage, enabling manufacturers to optimize their resource allocation. For instance, MES can automatically adjust production schedules to accommodate machine maintenance or workforce shifts, ensuring minimal disruptions. This level of optimization not only reduces waste but also increases the overall capacity utilization rate. Electronics manufacturers often report a 15-25% improvement in resource utilization after implementing MES, which translates into cost savings and improved production efficiency.

Unplanned downtime is a significant challenge in manufacturing, leading to lost productivity and increased operational costs. MES mitigates this issue through predictive maintenance capabilities, which use real-time data to identify potential equipment failures before they occur. Additionally, MES provides operators with immediate alerts and actionable insights to address issues quickly. In the electronics industry, where high-speed production lines and sensitive equipment are common, this capability is invaluable. Studies have shown that MES can reduce downtime by 30-50%, enabling manufacturers to maintain consistent production output and meet delivery timelines.

MES provides manufacturers with a centralized platform for accessing real-time production data, empowering decision-makers to respond swiftly to changing conditions on the shop floor. This level of visibility enables proactive adjustments to production schedules, inventory levels, and quality control measures. Enhanced data-driven decision-making contributes to increased overall efficiency, as manufacturers can quickly identify and resolve inefficiencies in the production process.

3.2 Areas of Manufacturing Most Impacted by MES

One of the primary areas where MES creates a significant impact is in production scheduling. Traditional manufacturing processes often rely on static scheduling methods that lack flexibility in responding to real-time disruptions. MES introduces dynamic scheduling capabilities that optimize workflows based on real-time data, including machine availability, workforce capacity, and material readiness. By doing so, MES minimizes delays, reduces idle time, and enhances production flow. This capability is particularly beneficial in industries like electronics manufacturing, where complex assembly lines and high variability in product designs demand agile and adaptive scheduling.

Quality control is a cornerstone of manufacturing, especially in sectors such as electronics, where precision and reliability are critical(Olu-lawal et al., 2024). MES integrates quality assurance processes directly into the production cycle, ensuring that products are monitored at every stage. Automated checks, real-time defect detection, and root cause analysis enable manufacturers to maintain high-quality standards while reducing rework and scrap. The ability to track and trace defects to specific processes or operators further enhances accountability and continuous improvement efforts. For instance, electronics manufacturers report significant improvements in first-pass yield rates and reduced costs associated with warranty claims post-MES implementation.

Efficient inventory management is essential to maintaining cost-effective and uninterrupted production. MES provides real-time visibility into inventory levels, material usage, and procurement needs. By tracking material flow across the production line, MES ensures that the right materials are available at the right time, minimizing stockouts and overstocking. This level of control is particularly impactful in just-in-time (JIT) manufacturing environments, where precise inventory management is crucial. In the electronics industry, where components are often expensive and time-sensitive, MES optimizes inventory handling, reduces waste, and supports lean manufacturing principles.

Another critical area influenced by MES is equipment utilization and maintenance. MES enables manufacturers to maximize the efficiency of their machinery by providing real-time data on equipment performance, utilization rates, and maintenance needs. Predictive maintenance capabilities help identify potential failures before they occur, reducing unplanned downtime and associated costs. This is particularly valuable in industries with high-speed production lines, such as electronics, where even short periods of downtime can disrupt supply chains and production schedules. Improved equipment utilization also extends the lifespan of machinery, contributing to long-term cost savings.

MES impacts workforce productivity by streamlining communication and enhancing collaboration between different roles in the manufacturing process. Operators, managers, and engineers can access real-time data on production status, allowing them to make informed decisions and resolve issues promptly. Additionally, MES reduces manual tasks and paperwork, enabling employees to focus on value-added activities. In the electronics industry, where precision and speed are paramount, MES empowers the workforce to maintain high productivity levels and respond effectively to dynamic production requirements.

Real-time monitoring is a hallmark feature of MES that significantly influences decision-making in manufacturing(Yadigarova, 2023). By providing a centralized platform for tracking production metrics, MES enables managers to identify inefficiencies and implement corrective actions swiftly. This capability supports a culture of continuous improvement, as manufacturers can analyze data trends, predict future challenges, and adapt their strategies accordingly. In fast-paced industries like electronics manufacturing, real-time insights are invaluable for maintaining competitiveness and meeting market demands.

3.3 How MES Impacts the Electronics Industry Versus Other Sectors

The electronics industry is characterized by highly complex products that often require frequent changes in design, configurations, and assembly processes. From printed circuit boards (PCBs) to consumer electronics, products in this sector demand precision and adaptability. MES plays a crucial role in managing these complexities by offering real-time monitoring of production processes and providing dynamic scheduling capabilities to handle varying production volumes and specifications. In electronics manufacturing, MES helps manage product configurations, track parts and components, and ensure accurate assembly through precise work instructions.

In contrast, the automotive industry, while also producing complex products, has a more standardized and repetitive production process. MES in automotive manufacturing focuses more on assembly line optimization and vehicle tracking, often emphasizing efficiency and throughput. For example, MES in automotive production lines is typically used to ensure the smooth flow of standardized components like engines, chassis, and other automotive parts through various assembly stages.

The electronics industry operates under rapid product innovation cycles, with frequent updates to technology and shorter product lifecycles. MES in electronics manufacturing is essential for speeding up production processes to meet market demand for the latest devices. By optimizing production scheduling and reducing downtime, MES allows manufacturers to stay competitive in an industry driven by fast-paced technological changes. Electronics manufacturers rely on MES for real-time data to make quick decisions and maintain high production flexibility, adapting rapidly to changes in consumer preferences or technological advancements.

In other sectors, such as pharmaceuticals, the pace of innovation is slower, and product lifecycles are longer due to the need for regulatory compliance, rigorous testing, and quality

ISSN 2086-7026 (Print), 2808-7372 (Online)

assurance. MES in pharmaceutical manufacturing focuses heavily on compliance tracking, batch management, and ensuring the integrity of the production process, such as adhering to Good Manufacturing Practices (GMP). The speed of production is important but not as critical as in electronics, as the sector does not face the same pressure for frequent product releases or market shifts.

The electronics industry places a high premium on quality control, given the sensitivity of its products to defects and failures(Bhanushali, 2023). Defects in electronics products, such as malfunctioning components, can have significant consequences, including product recalls and reputational damage. MES in electronics manufacturers is used to integrate quality control directly into the production process, enabling continuous monitoring of product quality at every stage. Automated defect detection, real-time alerts, and root cause analysis are common MES functionalities in electronics, ensuring that any deviations from the required standards are addressed promptly to avoid costly defects.

In contrast, the food and beverage industry also requires strict quality control but focuses more on hygiene, safety, and consistency of the product, with traceability systems in place to ensure product safety. MES in food and beverage production centers on managing inventory, monitoring expiry dates, and ensuring compliance with food safety standards, rather than tracking complex product defects at every stage of the production process. Though quality is critical in both sectors, electronics manufacturing typically faces a higher risk of defects impacting product functionality, making MES integration particularly focused on real-time quality assurance.

Efficient resource management is a priority for any manufacturing sector, but the specific needs differ. The electronics industry, with its high material costs and intricate supply chains, requires a high level of precision in resource utilization. MES helps manufacturers optimize raw material usage, minimize waste, and track component consumption throughout production. In electronics, where components such as semiconductors or microchips are expensive and limited in availability, MES is crucial for ensuring that materials are used efficiently and that production does not halt due to resource shortages.

In sectors such as textiles or consumer goods, the focus of MES is similarly on inventory and resource optimization but often involves less complex and less expensive materials. For example, in textiles, MES may be used to optimize the flow of raw materials like cotton or fabric, with less emphasis on real-time monitoring of expensive components. Therefore, while resource management is a universal benefit, the electronics industry requires a more detailed and granular level of control due to the higher costs and specialized nature of its inputs.

Compliance with regulations is a critical component of manufacturing in many sectors, but the specific requirements vary widely(Organization, 2024). In the electronics industry, regulatory compliance is primarily concerned with product safety standards, environmental regulations, and supply chain transparency, especially when dealing with materials like rare earth metals or hazardous substances. MES supports compliance by tracking production data, ensuring that products meet safety standards, and providing a digital trail of each manufacturing step for audit purposes.

In contrast, in industries like pharmaceuticals and food, regulatory compliance is more stringent, often requiring full traceability of each ingredient or component, especially for batch control. MES in these sectors is vital for ensuring that production processes adhere to regulatory frameworks such as FDA guidelines for pharmaceuticals or food safety standards. While both sectors require traceability, electronics manufacturing places more emphasis on supply chain tracking for components and materials sourced globally.

3.4 Challenges in MES Adoption and Potential Strategies for Mitigation

One of the most significant barriers to MES adoption is the high initial cost of implementation. The MES platform itself often requires a substantial upfront investment, including software licenses, hardware infrastructure, integration costs, and training for employees. Additionally, there are ongoing costs for system maintenance, updates, and support. For many small and medium-sized enterprises (SMEs), these costs may seem prohibitive, especially when the return on investment (ROI) is not immediately apparent.

To address the financial burden of MES adoption, manufacturers can consider phased implementation. Rather than deploying the system across the entire production floor at once, the MES can be implemented in stages, focusing first on critical areas that will benefit most from automation and data visibility. This approach allows manufacturers to spread out costs and generate early ROI from improved production processes that can offset further investments. Furthermore, manufacturers can explore financing options, such as leasing software or partnering with MES providers for flexible payment plans, to reduce the immediate financial impact.

Adopting MES often requires a significant shift in organizational culture(Tabim et al., 2024). Employees, particularly those accustomed to traditional, manual methods of production management, may resist the change. This resistance can manifest in various ways, including reluctance to adopt new technologies, fear of job displacement, or skepticism regarding the system's effectiveness. Furthermore, a lack of alignment between departments, such as production, IT, and management, can hinder the successful integration of MES into existing workflows.

Overcoming resistance to change requires strong leadership and effective communication. Manufacturing leaders should clearly articulate the benefits of MES adoption, emphasizing how the system will improve not only production efficiency but also the quality of work life for employees. Training programs that focus on user engagement and hands-on experience with the system can help employees feel more confident and comfortable with the new technology(Gwangwava, 2021). In addition, involving employees early in the selection and implementation process, providing them with a sense of ownership, and addressing their concerns can significantly reduce resistance. Management should also foster collaboration across departments to ensure that all relevant stakeholders are on board and understand the system's potential to improve operations.

Many manufacturing environments use a combination of legacy systems for managing various aspects of production, such as Enterprise Resource Planning (ERP) systems, supply chain management tools, and inventory control systems. Integrating MES with these pre-existing systems can be a complex task due to compatibility issues, data format discrepancies, or limited interoperability between platforms. Inadequate integration can lead to data silos, inconsistencies, and disruptions in the production process, undermining the benefits of MES.

To mitigate integration challenges, manufacturers should conduct a comprehensive assessment of their current systems and processes before selecting an MES solution(Shojaeinasab et al., 2022). This assessment will help identify compatibility requirements and determine whether any legacy systems need to be replaced or upgraded. MES providers that offer pre-built integration tools or APIs can streamline the process, reducing the complexity of connecting MES with other systems. Furthermore, working with experienced MES consultants or systems integrators who have expertise in integrating new technologies with legacy systems can significantly improve the integration process. Ensuring that all systems are compatible and share a common data language is key to maintaining seamless operations.

3.5 Implications of This Research

The research demonstrates that MES can significantly improve operational efficiency in electronics manufacturing by enhancing real-time data visibility, optimizing production scheduling, improving quality control, and reducing downtime. The implications of these findings suggest that electronics manufacturers can achieve higher throughput, reduce defects, and lower operational costs through the adoption of MES. This is particularly crucial for the electronics sector, which faces challenges such as rapid product innovation cycles, high-quality standards, and complex supply chains. The research highlights how MES helps streamline production processes, facilitating smoother workflows, and ensuring that resources are utilized optimally, ultimately increasing overall production efficiency.

For manufacturing managers and operations teams, the results emphasize the importance of MES in driving operational performance improvements. These improvements may lead to better customer satisfaction due to faster production cycles and fewer quality issues, thus enhancing the manufacturer's competitive edge.

This research underscores the strategic value of MES in improving decision-making processes within the electronics industry. By providing real-time insights into production data, MES helps managers make more informed decisions regarding resource allocation, inventory

ISSN 2086-7026 (Print), 2808-7372 (Online)

management, and process adjustments. The ability to monitor production activities and detect inefficiencies as they arise allows manufacturers to act quickly and avoid costly delays or defects. The research implies that manufacturers who invest in MES can strengthen their strategic decision-making capabilities, ultimately leading to greater business agility.

Moreover, the research suggests that MES can serve as a tool for long-term strategic planning by providing data that can inform forecasting, demand planning, and the scaling of production. This could be particularly beneficial for manufacturers looking to expand their operations or navigate fluctuating market conditions.

The research also contributes to the broader conversation on the adoption of Industry 4.0 technologies in manufacturing. MES represents a critical element in the digital transformation of the electronics industry, as it integrates various aspects of production into a cohesive, data-driven ecosystem. By adopting MES, manufacturers can align themselves with global trends toward automation, data-driven decision-making, and smart factories.

The findings imply that manufacturers should not only focus on the technical aspects of MES but also consider the organizational, cultural, and strategic implications of adopting such technologies. The integration of MES with other enterprise systems, such as Enterprise Resource Planning (ERP) and Supply Chain Management (SCM) software, is key to maximizing its effectiveness. This research provides valuable insights for manufacturers seeking to modernize their operations and adopt comprehensive digital strategies that enhance efficiency, reduce costs, and enable innovation.

The implementation of MES has significant implications for the competitive dynamics within the electronics industry. Companies that effectively adopt and integrate MES may achieve significant advantages over competitors who rely on traditional, manual, or disconnected production systems. The ability to produce products faster, at a higher quality, and with lower operational costs can position firms as market leaders in a highly competitive industry. The research suggests that manufacturers who invest in MES will not only improve internal operations but also create a more resilient and responsive organization, able to meet market demands more effectively.

For competitors in the industry, the research underscores the need to adopt similar technological solutions in order to stay competitive. In this context, MES adoption becomes a key strategic differentiator that can have a profound impact on long-term success in the electronics market.

The research also highlights the role of workforce training and development in the successful implementation of MES. For MES to yield maximum benefits, employees must be adequately trained to understand and utilize the system. This research implies that organizations should invest in comprehensive training programs to ensure that all relevant staff are equipped with the skills needed to operate and maintain the MES effectively. As automation and data-driven manufacturing practices become more widespread, the workforce will need to adapt to new roles that require technical proficiency in managing and interpreting data, ensuring quality, and overseeing machine operations.

Furthermore, the research suggests that as manufacturing environments become more automated, there may be shifts in job responsibilities and skill requirements. This opens up opportunities for retraining and reskilling workers, ensuring that they remain relevant and capable of thriving in the evolving manufacturing landscape.

This research opens the door for future studies in the area of MES and manufacturing technology. Future research could delve deeper into the specific technical challenges associated with MES adoption, such as system integration complexities, data security concerns, and scalability issues. Additionally, there is potential for exploring the effects of emerging technologies, such as artificial intelligence (AI) and the Internet of Things (IoT), on MES functionality and performance. Researchers can build on the findings of this study to develop new frameworks, tools, and methodologies that help companies more effectively implement and utilize MES.

Another avenue for future research could involve comparing MES adoption across different manufacturing sectors, examining the unique challenges and benefits in each industry. This would allow for a broader understanding of MES as a tool for production efficiency across diverse contexts, such as automotive, pharmaceutical, or consumer goods manufacturing.

4. CONCLUSION

This research has explored the impact of Manufacturing Execution System (MES) implementation on production efficiency in the electronics industry, providing valuable insights into how MES contributes to improving operational performance, enhancing decision-making, and driving competitive advantages in the sector. The findings clearly demonstrate that MES plays a critical role in increasing production efficiency by optimizing scheduling, improving real-time data visibility, reducing downtime, and enhancing quality control. These benefits, in turn, help electronics manufacturers streamline their processes, reduce operational costs, and meet the growing demands of an increasingly competitive and fast-paced market. The study also highlighted several challenges in adopting MES, including high initial costs, resistance to change, integration complexities, and data security concerns. However, it provided actionable strategies to mitigate these obstacles, such as phased implementation, employee engagement through training, and careful selection of compatible technologies. By overcoming these challenges, manufacturers can unlock the full potential of MES to create a more efficient, data-driven manufacturing environment. Furthermore, this research emphasized the need for manufacturers to adopt MES as part of their broader Industry 4.0 strategies, enabling them to stay competitive in an era defined by automation, digitalization, and smart manufacturing. The implications for future research are clear: further studies should investigate the specific technical and organizational barriers to MES adoption, as well as explore the integration of MES with emerging technologies like AI and IoT.

REFERENCES

Alarcón, M., Martínez-García, F. M., & de León Hijes, F. C. G. (2021). Energy and maintenance management systems in the context of industry 4.0. Implementation in a real case. *Renewable and Sustainable Energy Reviews*, *142*, 110841.

Bäck, A. (2019). *Data driven decision making in Industrial Control Systems*.

Bhanushali, A. (2023). Ensuring Software Quality Through Effective Quality Assurance Testing: Best Practices and Case Studies. *International Journal of Advances in Scientific Research and Engineering*, *26*(1).

Brint, A., Genovese, A., Piccolo, C., & Taboada-Perez, G. J. (2021). Reducing data requirements when selecting key performance indicators for supply chain management: The case of a multinational automotive component manufacturer. *International Journal of Production Economics*, *233*, 107967.

Calabrese, A., Levialdi Ghiron, N., & Tiburzi, L. (2021). 'Evolutions' and 'revolutions' in manufacturers' implementation of industry 4.0: a literature review, a multiple case study, and a conceptual framework. *Production Planning & Control*, *32*(3), 213–227.

Clausen, P. (2023). Towards the industry 4.0 agenda: Practitioners' reasons why a digital transition of shop floor management visualization boards is warranted. *Digital Business*, *3*(2), 100063.

Elliott, R. (2013). *Manufacturing execution system (MES) an examination of implementation strategy*. California Polytechnic State University.

Gera, R. (2012). Bridging the gap in knowledge transfer between academia and practitioners. *International Journal of Educational Management*, *26*(3), 252–273.

Gliner, J. A., Morgan, G. A., & Leech, N. L. (2011). *Research methods in applied settings: An integrated approach to design and analysis*. Routledge.

Gomes, C., Busanello, E., Padilha, B., Lerman, L. V., & Tabim, V. M. (2024). Exploring Key Factors for Implementing Manufacturing Execution Systems (MES) within the Framework of Industry 4.0 for Small and Medium-Sized Enterprises (SMEs) in the Manufacturing Sector. *Production*, *34*, e20230085.

Gwangwava, N. (2021). Learning design thinking through a hands-on learning model. *International Journal of Innovative Teaching and Learning in Higher Education (IJITLHE)*, *2*(1), 1–19.

Hahn, A., Ashok, A., Sridhar, S., & Govindarasu, M. (2013). Cyber-physical security testbeds: Architecture, application, and evaluation for smart grid. *IEEE Transactions on Smart Grid*, *4*(2), 847–855.

Haun, J. N., Schneider, T., Ballistrea, L. M., McMahon-Grenz, J., Melillo, C., Benzinger, R., & Paykel, J. M. (2024). Veterans' lived experiences with the VA's Whole Health system and perceived impact on dimensions of wellness. *EXPLORE*, *20*(4), 554–561.

Karnouskos, S., Savio, D., Spiess, P., Guinard, D., Trifa, V., & Baecker, O. (2010). Real-world service interaction with enterprise systems in dynamic manufacturing environments. *Artificial Intelligence Techniques for Networked Manufacturing Enterprises Management*, 423–457.

López, M. E., Göen, T., Mol, H., Nübler, S., Haji-Abbas-Zarrabi, K., Koch, H. M., Kasper-Sonnenberg, M., Dvorakova, D., Hajslova, J., & Antignac, J.-P. (2021). The European human biomonitoring platform-design and implementation of a laboratory quality assurance/quality control (QA/QC) programme for selected priority chemicals. *International Journal of Hygiene and Environmental Health*, *234*, 113740.

ISSN 2086-7026 (Print), 2808-7372 (Online)

Mantravadi, S., & Møller, C. (2019). An overview of next-generation manufacturing execution systems: How important is MES for industry 4.0? *Procedia Manufacturing*, *30*, 588–595.
Mantravadi, S., Srai, J. S., & Møller, C. (2023). Application of MES/MOM for Industry 4.0 supply chains: A cross-case analysis. *Computers in Industry*, *148*, 103907.
Nessim, C., El Hamd, M., Obaydo, R., Saleh, S., & Lotfy, H. (2024). KPI-based standards benchmarking for the preference of different analytical approaches developed for simultaneous determination of ciprofloxacin and hydrocortisone: A SWOT case study. *Reviews in Analytical Chemistry*, *43*(1), 20230077.
Olsson, J. G., & Xu, Y. (2018). *Industry 4.0 adoption in the manufacturing process: multiple case study of electronic manufacturers and machine manufacturers*.
Olu-lawal, K. A., Olajiga, O. K., Ani, E. C., Adeleke, A. K., & Montero, D. J. P. (2024). The role of precision metrology in enhancing manufacturing quality: a comprehensive review. *Engineering Science & Technology Journal*, *5*(3), 728–739.
Organization, W. H. (2024). *Quality assurance of pharmaceuticals: a compendium of guidelines and related materials. Volume 2. Good manufacturing practices and inspection*. World Health Organization.
Pina, E., Ramos, J., Jorge, H., Váz, P., Silva, J., Wanzeller, C., Abbasi, M., & Martins, P. (2024). Data privacy and ethical considerations in database management. *Journal of Cybersecurity and Privacy*, *4*(3), 494–517.
Shojaeinasab, A., Charter, T., Jalayer, M., Khadivi, M., Ogunfowora, O., Raiyani, N., Yaghoubi, M., & Najjaran, H. (2022). Intelligent manufacturing execution systems: A systematic review. *Journal of Manufacturing Systems*, *62*, 503–522.
Tabim, V. M., Ayala, N. F., Marodin, G. A., Benitez, G. B., & Frank, A. G. (2024). Implementing Manufacturing Execution Systems (MES) for Industry 4.0: Overcoming buyer-provider information asymmetries through knowledge sharing dynamics. *Computers & Industrial Engineering*, *196*, 110483.
Westphal, L. E. (2002). Technology strategies for economic development in a fast changing global economy. *Economics of Innovation and New Technology*, *11*(4–5), 275–320.
Wilson, A. J., Brown, N., Rand, E., & Genever, P. G. (2023). Attitudes towards standardization of mesenchymal stromal cells—a qualitative exploration of expert views. *Stem Cells Translational Medicine*, *12*(11), 745–757.
Yadigarova, S. A. (2023). *Condition Monitoring and Data Collection System*. Khazar University (Azerbaijan).