Proceeding
3rd International Conference on Multidisciplinary Studies
Universitas Riau Kepulauan, Batam, November 23, 2025

E-ISBN :
E-ISSN : 3047-6399
Volume 3 : 59-65

LITERATURE REVIEW IMPLEMENTATION AND CHALLENGES OF FLEXIBLE MANUFACTURING SYSTEM IN ENHANCING INDUSTRY 4.0 COMPETITIVENESS

Erona Indah R[1], Lux Sania L[2], Tri Sugihartati[3], Idil Fitri[4], Fadhlurrahman Hafizh[5]

[1, 2 , 3, 4, 5] *Industrial Engineering, Faculty of Engineering, University Riau Kepulauan, Batam, Indonesia*

Corresponding author: eronaindah@gmail.com,

Abstract

A Flexible Manufacturing System (FMS) is a key paradigm in modern manufacturing, characterized as an integrated system capable of adapting to internal and external changes. Its core lies in the ability to shift to producing new products typical of small- to medium-batch manufacturing. This study integrates three main pillars of FMS: (1) Conceptualization and Flexibility Control, (2) Performance Analysis through Simulation, and (3) Integration with Industry 4.0 Technologies. Discrete-event simulation tools such as Petri Nets and Visual Slam AweSim are essential for accurate performance analysis due to the complexity of FMS component interactions. Industry 4.0 technologies, including IoT, AI, and Autonomous Mobile Robots (AMR) or Automated Guided Vehicles (AGV), further enhance overall flexibility and optimize intralogistics. However, full FMS implementation faces major challenges related to cost and complexity, particularly for Small Scale Industries (SSI). This paper provides a holistic review for understanding and leveraging FMS in the digital era.

Keywords : Flexible Manufacturing System, Advanced Manufacturing Technology, Smart Manufacturing.

INTRODUCTION

Definition and Classification of FMS is recognized as a highly integrated and complex manufacturing system designed to respond flexibly to changes. Kapitanov (2017) specifically defines flexibility as the system's ability to switch to the production of new products typical for small-batch manufacturing. Wulandari et al. (2021) emphasize that FMS, along with other AMT (JIT, Cellular Manufacturing), positively impacts the control of manufacturing operations. Performance Analysis and Modeling: Considering the sophisticated and costly nature of FMS, El-Tamimi et al. (2012) highlight that pure mathematical programming approaches are difficult to implement. Therefore, simulation has become the dominant method for analyzing performance measures, with Petri Nets identified as an effective modeling technique for handling concurrency and deadlocks.

FMS in the Context of Industry 4.0: Javaid et al. (2022) confirm that the implementation of Industry 4.0 technologies (IoT, AI, Cloud Computing) has enhanced the overall flexibility of manufacturing systems. Studies by Vlachos et al. (2022) and Fragapane et al. (2022) specifically demonstrate the significant role of Autonomous Mobile Robots (AMR) and Automated Guided Vehicles (AGV), strengthened by IoT, in creating smart intralogistics capable of improving throughput and route flexibility. Implementation Challenges Critical research by Khan et al. (2023) highlights adoption gaps, especially in Small-Scale Industries (SSI), which are hindered by high investment costs, issues in integrating machine tools, and the lack of resources for advanced

Procceding ICMS © 2025 by Universitas Riau Kepulauan is licensed under Creative Commons Attribution-ShareAlike 4.0 International

control and maintenance.

Rapidly changing global market demands (volatile) and increased product customization have driven companies to adopt production systems capable of balancing high product variety with high productivity. Economic globalization specifically demands increasingly tighter competitiveness. FMS emerges as a vital solution to address these challenges. As one of the Advanced Manufacturing Technologies (AMT) Wulandari et al. (2021), FMS enables companies to reduce setup time and transition time from one product type to another. This capability, known as manufacturing flexibility, directly enhances the company’s ability to respond promptly to customer demand and increase throughput without incurring excessive resource costs. The integration of this technology is further refined with the advent of Industry 4.0.

METHODOLOGY

Manufacturing flexibility is rooted in the need to respond to market uncertainties. The theory states that a system’s adaptability can be quantified and enhanced. Definition Flexibility is the ability of a production system to maintain performance in the face of operational or environmental changes. Kapitanov (2017) further conceptualizes it as the capability to transition to the production of new products. The theory recognizes that flexibility is not a singular concept but a multidimensional construct. Kapitanov (2017) identifies key dimensions relevant to FMS, which include:

1. Routing Flexibility: The system’s capability to process parts through alternative paths, which theoretically reduces the risk of bottlenecks and downtime.
2. Machine Flexibility: The ability of machines to process various types of parts, forming the foundation of FMS.
3. Product Flexibility: The system’s ability to introduce new products quickly and efficiently.

Flexibility Control is based on the principle that flexibility must be measured (through the geometric mean of equipment and component flexibility) and managed, often by dividing the system into classes to facilitate optimal trade-off decisions between cost and capability. This study also highlights four main dimensions of FMS performance improvement, namely economic, social, environmental, and sustainability dimensions. The functions of these four key dimensions for FMS:

1. Economic: cost efficiency and productivity improvement.
2. Social: enhancement of worker skills and safety.

Procceding ICMS © 2025 by Universitas Riau Kepulauan is licensed under Creative Commons Attribution-ShareAlike 4.0 International

3. Environmental: reduction of waste and energy consumption.
4. Sustainability: a production system resilient to long-term changes.

.

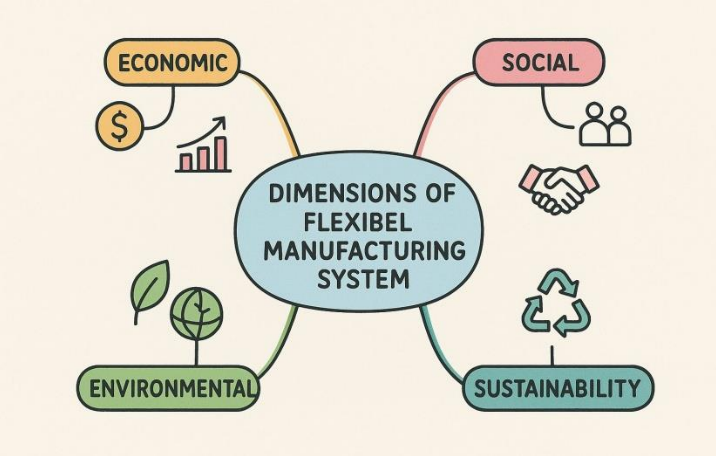

Figure 1. Flexible Industry 4.0 Dimensions to Support FMS Javaid, M. et al. (2022)

Smart Manufacturing and Industry 4.0 Theory

This theory focuses on the convergence of physical and cyber systems (Cyber-Physical Systems - CPS) in production. Cyber-Physical Systems (CPS): Industry 4.0 transforms FMS into CPS, where physical components (machines, robots, AGV) are connected with cyber components (IoT, Cloud, AI). This connectivity enables decentralized decision-making and real-time adaptation. Autonomous Intralogistics: The use of AMR/AGV is based on autonomous and multi-agent system theory. In this theory, logistics units (AGV) operate independently (autonomously) but coordinate through a cyber network (IoT) to optimize overall material flow, rather than just individual movements. Cloud computing theory provides the concept of computational resource elasticity. This allows FMS to leverage auto-scaling services that automatically adjust control data processing capacity according to fluctuations in production load, fundamentally enhancing the operational flexibility of the control system.

Main Modeling Techniques

1. Petri Nets used to model, measure, and analyze FMS performance metrics. Petri Nets are highly effective in modeling concurrency (parallel processing) and synchronization (process dependencies) among components, as well as helping to prevent and avoid deadlocks El-Tamimi et al. (2012).
2. Simulation Software (Visual Slam AweSim) advanced simulation software such as Visual Slam AweSim is used to model discrete event flows, providing clear visual and quantitative results El-Tamimi et al. (2012).

Procceding ICMS © 2025 by Universitas Riau Kepulauan is licensed under Creative Commons Attribution-ShareAlike 4.0 International

3. Bottleneck Analysis this technique is applied to identify workstations that most limit system throughput. Bottleneck analysis results are often used to validate simulation outcomes or as a benchmark El-Tamimi et al. (2012).

Critical Issues and Implementation Challenges in Case Studies: Small Scale Industries (SSI)

The full implementation of Flexible Manufacturing Systems (FMS) requires the integration of advanced technologies, such as computerized machine tools, automated material handling systems (eg, AGV/AMR), and centralized control systems. These conditions create significant barriers to entry for Small-Scale Industries (SSI) Khan, M.M. et al. (2023). Although the literature acknowledges that FMS improves productivity and provides competitive advantages, the majority of SSI in developing countries are still unable to fully leverage FMS due to main issues.

Financial Challenges and Very High Initial Costs

The primary and most fundamental challenge for SSI is the substantial initial capital investment. Expensive Components, a full FMS requires significant investment in advanced and costly components, including industrial robots, state-of-the-art Computer Numerical Control (CNC) machine tools, and automated intralogistics systems. Investment Risk for SSI with tighter financial margins, the risk of project failure or slow return on investment (ROI) becomes an intolerable burden.

Technical Complexity and Measurement Issues

FMS is a highly integrated and complex system, and this complexity triggers specific technical challenges for SSI. Machine Tool Issues, SSI often use older or less advanced equipment. Integrating this equipment into a centralized, real-time FMS network is very difficult. FMS demands high standardization and accuracy at each workstation. Advanced Control and Maintenance Issues, FMS requires advanced automatic control techniques, including dynamic scheduling systems, automatic part recognition systems, and real-time monitoring systems. SSI often lack the software and expertise to manage these complex control systems. FMS requires predictive and preventive maintenance supported by sensor data. SSI often do not have the budget or trained personnel for maintaining such advanced technologies. Flexibility Quantification Issues, SSI face difficulties in measuring and quantifying the level of flexibility achieved or required (such as routing, machine, or product flexibility). Without clear metrics, it is challenging to determine whether the FMS investment provides commensurate value.

Human Resource Limitations (Human Element)

The implementation of FMS requires a fundamental transformation of workforce skills. Human-related issues in SSI. Skills Shortage: SSI workforces may lack the necessary skills to operate, program, or repair CNC machines and robots. The need for system engineers and robotics technicians represents a new burden for SSI. Resistance to Change: Transitioning from traditional manufacturing systems to FMS requires cultural and organizational adaptation. Long-standing employees may resist new technologies due to fear of job loss or lack of understanding. High Training Costs: The time and cost required to retrain the entire workforce to be proficient in FMS and Industry 4.0 technologies (AI, IoT) are often prohibitively high for SSI.

RESULT AND DISCUSSION

FMS Performance Analysis Through Simulation

Simulation has become the primary tool for analyzing performance measures (such as throughput, machine utilization, and work-in-progress) of FMS Avoiding Losses Simulation allows analysis without financial, resource, or labor losses, which is crucial given the sophisticated and costly components of FMS. Modeling Complexity Simulation can dynamically and stochastically mimic system behavior, including queues, machine breakdowns, and dispatching rules.

Recommended Adaptive Solutions for SSI

To address these challenges, studies suggest that SSI adopt a gradual (Incremental FMS) or modular FMS approach. Focus on Partial Flexibility: SSI can choose to focus only on the types of flexibility most critical to their business model, such as improving routing flexibility through a simple cellular layout rather than installing full scale AGV. Leverage Affordable Industry 4.0 Technologies: Using relatively inexpensive IoT sensors and Cloud Computing services for simple data monitoring can provide operational flexibility improvements without large investments in advanced robotics. Khan, M.M. et al. (2023)

Table 1. Methods Used in FMS Reference Papers

No.	Paper Title	Author	Method Used
1	Dampak Sistem Manufaktur Fleksibel pada Teknologi Manufaktur Maju	Wulandari, J.et al. (2021)	Literature/Conceptual Study (Discussing FMS based on the shift from job-order costing to process costing, as well as reviewing the implementation of Just In Time, Cellular Manufacturing, and Total Quality Control).

Procceding ICMS © 2025 by Universitas Riau Kepulauan is licensed under Creative Commons Attribution-ShareAlike 4.0 International

2	Increasing Flexibility and Productivity in Industry 4.0 Production Networks with Autonomous Mobile Robots and Smart Intralogistics	Fragapane, G. et al. (2022)	Analytical Model (Developing and testing an analytical model for throughput analysis and comparing an Autonomous Mobile Robot (AMR) based production network with a traditional production line).
3	Smart and Flexible Manufacturing Systems using Autonomous Guided Vehicles (AGVs) and the Internet of Things (IoT)	Vlachos, I. et al. (2022)	In-Depth Case Study (Conducting a case study in a manufacturing company to examine the impact of integrating Autonomous Guided Vehicles (AGV) with the Internet of Things (IoT).
4	Enabling Flexible Manufacturing System (FMS) Through the Applications of Industry 4.0 Technologies	Javaid, M. et al. (2022)	Literature/Conceptual Review (Discussing and examining various dimensions and Industry 4.0 technologies (IoT, AI, Big Data, etc.) and their implementation to enhance FMS performance).

The most efficient application of FMS in manufacturing companies is a combination of careful planning and appropriate operational technology for Industry 4.0 enterprises. Operational & Physical Efficiency Vlachos, I. et al. (2022) and Javaid, M. et al. (2022) provide guidance for implementing technologies (AGV, IoT, AI, Big Data) that accelerate physical workflow and significantly enhance production flexibility.

CONCLUSION AND SUGGESTION

This study confirms that the Flexible Manufacturing System (FMS) is a highly advanced and integrated production system designed to provide high flexibility in manufacturing environments. Definitively, FMS is a combination of computer-controlled machine tools (CNC), automated material handling systems (such as AGV or conveyors), and a central computer control system that manages the entire operation. At its core, FMS has the ability to respond flexibly to changes, whether in the type of products being manufactured (machine flexibility) or the sequence of production processes (routing flexibility). FMS fills a critical gap in the manufacturing industry, where it is most effectively applied to medium-volume production with high product variety, as commonly seen in the automotive, electronics, and aerospace sectors. The implementation of FMS presents significant challenges that must be addressed, particularly during the initial stages. The primary challenge is the very high initial investment required for purchasing automated equipment and complex integration software. In addition, implementing FMS requires substantial and detailed pre-planning to ensure seamless system integration, as well as a skilled workforce capable of managing, maintaining, and programming these advanced technologies. Although FMS demands a substantial initial capital investment, it provides considerable long-term operational cost benefits. FMS is designed to reduce the cost per unit produced through automation, dramatically minimizing the need for direct labor. The system also

Procceding ICMS © 2025 by Universitas Riau Kepulauan is licensed under Creative Commons Attribution-ShareAlike 4.0 International

optimizes material and information flows, resulting in significant reductions in work-in-progress inventory and storage costs. Improved machine efficiency and reduced overall setup time further contribute to better resource utilization. Overall, the impact of FMS is highly transformative for a company's competitiveness. Its primary effects are increased flexibility and productivity. FMS enables companies to respond quickly to dynamic market demands, product design changes, and fluctuations in order volumes. Additionally, with precise automated control, FMS ensures consistent product quality and reduces defect rates. With the ability to produce a wide range of products quickly and efficiently at lower operational costs, FMS serves as a critical strategy that provides strong competitive advantages in today's global market, enabling companies to remain relevant and adaptive in the Industry 4.0 era.

REFERENSI

El-Tamimi, A.M., Abidi, M.H., Mian, S.H., & Aalam, J. (2012). Analysis of performance measures of flexible manufacturing system. *Journal of King Saud University - Engineering Sciences*, 24(2), 115-129.

Fragapane, G., Ivanov, D., Peron, M., Sgarbossa, F., & Strandhagen, J.O. (2022). Increasing flexibility and productivity in Industry 4.0 production networks with autonomous mobile robots and smart intralogistics. *Annals of Operations Research*, 308, 125-143.

Javaid, M., Haleem, A., Singh, R.P., & Suman, R. (2022). Enabling flexible manufacturing system (FMS) through the applications of industry 4.0 technologies. *Internet of Things and Cyber-Physical Systems*, 2, 49-62.

Kapitanov, A.V. (2017). Manufacturing System Flexibility Control. *Procedia Engineering*, 206, 1470-1475.

Khan, M.M., Singh, K.P., & Khan, W.U. (2023). A critical study on the implementation of operation, control and maintenance techniques for flexible manufacturing systems in small scale industries. *Materials Today: Proceedings*.

Ojstersek, R, Acko, B, & Buchmeister, B. Simulation study of a flexible manufacturing system regarding sustainability. (2020).

Vlachos, I., Pascazzi, R.M., Ntotis, M., Spanaki, K., Despoudi, S., & Repoussis, P. (2022). Smart and flexible manufacturing systems using Autonomous Guided Vehicles (AGVs) and the Internet of Things (IoT). *International Journal of Production Research*, 1-22.

Wulandari, J., Oktaviani, M., & Mellani, P. (2021). Dampak Sistem Fleksibel Manufaktur Pada Teknologi Manufaktur Maju. *Jurnal Pendidikan Tambusai*, 5(2), 3132-3137.

Procceding ICMS © 2025 by Universitas Riau Kepulauan is licensed under Creative Commons Attribution-ShareAlike 4.0 International