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FLEXIBLE, SMART MANUFACTURING SYSTEMS AND INDUSTRIAL ENERGY MANAGEMENT SYSTEM IN AUTOMOTIVE FIELD

Demetrius PETRESCU (DUBIC), Oana Roxana CHIVU, Anamaria Ioana FEIER, Marilena GHEORGHE

Abstract: *In one word, to improve productivity, sustainability, and efficiency, the automotive industry is putting more and more emphasis on smart manufacturing, flexible manufacturing, and industrial energy management systems. Two important areas of development to handle the potential and challenges in this industry are the identification of energy flexibility measures and the incorporation of modern technology. An industrial energy management system (IMES) designed to meet the specific needs of the automobile industry must have several essential elements to manage energy in production facilities.*
Keywords: *Flexible, Smart Manufacturing Systems in the Automotive Field, automotive industry, Industrial Energy Management Systems, Energy Productivity*

1. INTRODUCTION

In the automotive industry, flexible, smart manufacturing systems (FSMS) are complex production systems that combine automation, robotics, artificial intelligence (AI), and the Internet of Things (IoT) to improve productivity, efficiency, and adaptability in the car manufacturing industry. Real-time data collecting, self-optimization, and quick reconfiguration are made possible by these systems to adapt to new technologies, customization, and shifting production demands.
Flexible Manufacturing Systems (FMS):

- Integration with IIoT: The automobile industry's flexible production systems use the Industrial Internet of Things (IIoT) to improve system-to-system communication, allowing manufacturers to make dynamic process adjustments and competitiveness [1].
- Automation and Robotics: For scheduling and operational management in flexible manufacturing systems, the transition from conventional production systems based on automation, robotics, and cybernetics is essential [2].
- Material Handling with AIVs: To increase industrial processes' efficiency and flexibility, material handling systems incorporate Autonomous Intelligent Vehicles (AIVs) to decrease manual labor [3, 4].
- RFID Technology: By integrating RFID technology with FMS, items may be tracked during the production process, increasing control and productivity [5].
- Dynamic Production Planning: Optimizing key performance indicators (KPIs) in flexible manufacturing requires intelligent production planning that incorporates adaptive operating speeds and dynamic usage of machine capabilities [6].

Smart Manufacturing Systems:

- Industry 4.0 Technologies: Manufacturing processes are being transformed into intelligent, dependable, and adaptable systems using Industry 4.0 technologies like digital twins, the Internet of Things, and collaborative robots [7, 8].
- Adaptive Reconfiguration: Smart manufacturing environments utilize adaptive, highly repeatable, and rapid auto-reconfiguration processes to handle variations in product types and assembly processes efficiently [9].
- Collaborative Systems: The integration of human and automated resources into

collaborative smart manufacturing systems enhances flexibility, efficiency, and operator satisfaction [10].

Industrial Energy Management Systems in the Automotive Field. Energy Management Strategies:

- Energy Monitoring Systems: Implementing energy monitoring and data logging systems helps in planning and improving energy efficiency by providing detailed consumption data [11].
- Energy Flexibility: Identifying and characterizing energy flexibility measures in industrial systems allows for optimized energy-associated production costs and supports the integration of renewable energy sources [12 ,13].
- Decision-Making in Energy Management: Advanced energy management systems incorporate decision-making functionalities for energy-integrated production scheduling, optimizing energy consumption and production throughput [14].
- AI and Machine Learning: AI-driven energy management systems dynamically control and allocate energy resources, enhancing overall vehicle performance and energy efficiency [15].

Case Studies and Applications:

- Auto Part Manufacturing: A numerical case study in an auto part manufacturing plant demonstrated the benefits of energy-integrated production scheduling, highlighting improvements in energy consumption and cost efficiency [14].
- Hybrid and Electric Vehicles: Energy management strategies for hybrid and electric vehicles focus on optimizing the split power between internal combustion engines and electric machines to minimize fuel consumption and emissions [16 ,17].

Automotive producers may drastically cut energy expenses, carbon footprints, and overall operational efficiency by putting these energy management strategies into practice.

By integrating flexible manufacturing systems with smart technologies and implementing advanced energy management strategies, the automotive industry can achieve higher efficiency, adaptability, and sustainability.

Table 1

Flexible Manufacturing Systems vs. Industrial Energy Management Systems.

Aspect	Flexible Manufacturing Systems	Industrial Energy Management Systems
Technologies	IIoT, Automation, Robotics, AIVs, RFID	Energy Monitoring, AI, Machine Learning
Key Features	Dynamic Adaptation, Intelligent Planning, Collaborative Systems	Energy Flexibility, Decision-Making, Optimization
Applications	Automotive Production, Material Handling	Auto Part Manufacturing, Hybrid/Electric Vehicles

IMES guarantees sustainability and energy efficiency, while FMS improves industrial flexibility and automation. While both systems aid in operational improvement, their primary functions in industrial settings are different.

2. IMPORTANT ELEMENTS OF AUTOMOTIVE FLEXIBLE MANUFACTURING SYSTEMS

Flexible Manufacturing Systems (FMS) for the automotive industry are made to effectively manage production fluctuations while preserving high levels of productivity.

Key elements of an Automotive FMS

- Flexibility in Production Facilities: Flexible Manufacturing Systems (FMS) in the automotive industry enable high flexibility in managing production facilities and resources, allowing for efficient small batch production [1]. Integration of IoT: FMS incorporates the Industrial Internet of Things (IoT) to enable communication between systems, contributing to the ultimate flexibility required for competitiveness in the global market [2].
- Material Handling Systems: Research has focused on integrating material handling systems with Autonomous Intelligent Vehicles (AIV) to automate and streamline material movement in manufacturing environments, enhancing flexibility [3].

To enhance production processes, smart manufacturing makes use of cutting-edge technology including artificial intelligence (AI), the Internet of Things (IoT), big data analytics, automation, and cloud computing.

Contribution of Smart Manufacturing to Efficiency and Productivity:

- Technological Advancements: Smart manufacturing, utilizing technologies such as cyber-physical systems, artificial intelligence, and digital twins, offers opportunities for increased productivity and resource efficiency in automotive production [4].
- Improved Manufacturing Performance: The integration of interconnected machines and tools in smart manufacturing aims to optimize energy and workforce requirements, leading to enhanced manufacturing performance [5].
- Potential Benefits: Smart manufacturing systems have the potential to reduce costs, improve production flexibility, and increase energy efficiency in the automotive industry [6].

Challenges and Opportunities in Implementing Industrial Energy Management Systems:

- Energy Savings Opportunities: There are significant energy savings opportunities in automotive manufacturing and its supply chain, with key concepts summarized from a database including top energy saving recommendations and implemented measures [7].
- Commercial Packages: A brief survey on existing commercial packages of industrial energy management systems by different vendors highlights the interest in optimizing energy-associated production costs and supporting the energy transition towards renewable sources [8].
- Energy Flexibility Measures: A proposed methodology aims to identify and characterize available energy flexibility measures in industrial systems, providing a qualitative and quantitative understanding of capabilities for energy flexible operation [9].

Key Features of an Industrial Energy Management System for Automotive Manufacturing Plants. *Real-Time Monitoring and Optimization*

- Real-Time Data Collection: Continuous monitoring of energy consumption across various processes and equipment is essential. This includes tracking key parameters of engines, turbines, and other machinery to ensure optimal performance [11].
- Real-Time Optimization: The EMS should support real-time decision-making to optimize energy use, such as adjusting production schedules and machinery operations based on current energy demands and availability [12, 13].

Integration with Production Scheduling

- Energy-Integrated Production Scheduling: The EMS should integrate energy management with production scheduling to optimize both energy consumption and production throughput. This involves modeling performance metrics for operational optimization [14].
- Simulation-Based Design: Utilizing simulation tools to design and optimize the layout and operation of automated systems, such as Automated Guided Vehicles (AGVs), can enhance energy efficiency and production throughput [15].

Performance Metrics and Indicators

- Key Performance Indicators (KPIs): Monitoring KPIs related to energy consumption, cost, and production efficiency is crucial. These indicators help in setting and achieving energy efficiency targets [12, 16].
- Energy Performance Indicators (EPIs): Developing and using EPIs to benchmark energy performance against industry standards can motivate improvements and track progress [16,17].

Sustainability and Carbon Management

- Carbon Performance: The EMS should support the adoption of low-carbon production practices and improve carbon performance by reducing energy use and switching to less carbon-intensive energy sources [18].
- Sustainable Manufacturing Practices: Implementing holistic energy modeling and sustainable manufacturing methods can significantly improve environmental performance [19,20].

Advanced Control Systems

- Autonomous Control: The EMS should be capable of autonomous operation, continuously improving its ability to assess, predict, and act to enhance energy sustainability [13].
- Manual and Automated Control: Combining automated recommendations with manual control options allows operators to make informed decisions based on real-time data and system suggestions [11].

Energy Efficiency Techniques

- Energy Efficient Techniques: Developing and implementing energy-efficient techniques in manufacturing operations is crucial to reduce energy consumption and greenhouse gas emissions [21].
- Optimization of Energy Use: Techniques such as optimizing the use of cogeneration systems and implementing energy-efficient production sequences can lead to significant energy savings [11,19].

These features collectively ensure that an IMES tailored for automotive manufacturing plants can effectively manage energy consumption, reduce costs, and improve environmental performance.

Table 2

Energy Efficiency Techniques.

Feature	Description	Citations
Real-Time Monitoring and Optimization	Continuous data collection and real-time decision-making for optimal energy use	[11,12, 13]
Integration with Production Scheduling	Energy-integrated scheduling and simulation-based design for efficiency	[14, 15]
Performance Metrics and Indicators	Monitoring KPIs and developing EPIs for benchmarking and improvement	[12,16, 17]
Sustainability and Carbon Management	Supporting low-carbon practices and sustainable manufacturing methods	[18,19, 20]
Advanced Control Systems	Autonomous and manual control for continuous improvement	[11, 13]
Energy Efficiency Techniques	Implementing energy-efficient techniques and optimizing energy use	[11,19,21]

Latest Advancements in Smart Manufacturing Systems for Automotive Production:

- Technological Integration: The latest advancements in smart manufacturing systems involve the integration of big data processing, artificial intelligence, and advanced robotics to enhance manufacturing performance and energy optimization [5].
- Strategic Analysis Framework: A strategic analysis framework has been developed to estimate cost-effective improvements in energy efficiency and productivity through smart manufacturing, using the cost of conserving energy (CCE) as a complementary measure [10].
- Focus on Energy Productivity: Efforts in craft breweries to use smart manufacturing for reducing energy intensity and increasing product yield demonstrate the potential benefits of smart manufacturing in improving energy productivity [10].

Flexible, intelligent manufacturing systems and industrial energy management have been greatly improved by recent developments in Industry 4.0 technologies.

Important advancements consist of:

1. Integration of 5G with Edge Computing: The implementation of 5G networks in conjunction with edge computing enables real-time decision-making by lowering latency and facilitating immediate data processing. In manufacturing settings, this integration maximizes operational effectiveness and safety.
2. Use of Collaborative Robots (Cobots): Cobots are made to operate alongside human operators, improving productivity, safety, and accuracy. By automating dangerous or repetitive processes, its use lowers hazards and boosts operational effectiveness.
3. Predictive management Using AI and IoT: Manufacturers can anticipate equipment problems before they happen by utilizing artificial intelligence and the Internet of Things. This proactive strategy prolongs the life of machines and reduces unscheduled downtime.

4. Developments in Manufacturing Execution Systems (MES): Cloud-based solutions, IIoT device integration, and artificial intelligence (AI) capabilities are all being included into modern MES. By coordinating each stage of the production process and facilitating real-time monitoring, predictive maintenance, and enhanced quality control, these systems serve as the brains of a contemporary factory.
5. Sustainability and Green Manufacturing: By increasing energy efficiency and cutting waste, Industry 4.0 technologies make it possible for more environmentally friendly production methods. Businesses are using green practices to lessen their influence on the environment and to support global sustainability objectives.

These developments promote Industry 4.0's objectives by making production processes more flexible, effective, and ecologically friendly.

3. CASE STUDY OF ASSEMBLY LINE

The machine can automatically assemble the finished Light Dome Switch; it currently has operating settings for the PQ35 and MQB models. Eight distinct stations comprise the machine, which is separated into two separate functional components.

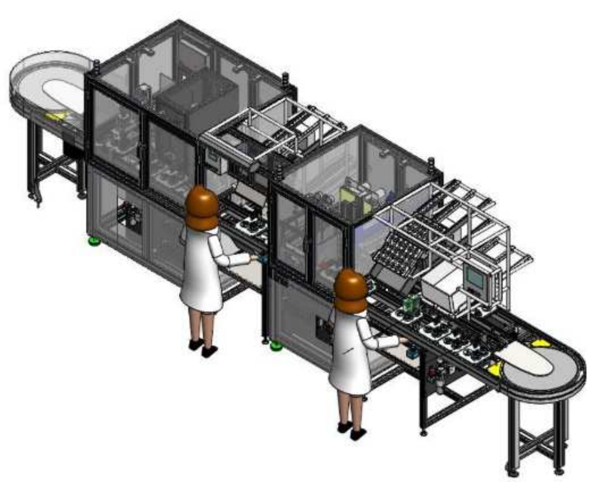

Fig. 1. Assembly line [26]

The machine's primary menu, shown in Figure 2, allows the operator to view, control, and select the many functions.

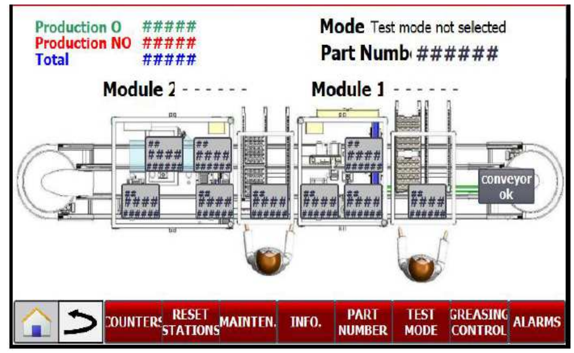

Fig. 2. The menu of assembly line [26]

According to Figure 2, from top to bottom, in sequence of appearance:

- Production O: the production counter of sufficient pieces.
- Production NO: counter of the production's defective parts
- Total: the sum of all the parts that were made.
- Mode: the machine's currently selected operating mode
- Part number: the product's actual reference.

The working modes of Modules 1 and 2 are adjacent to the label, respectively.

Given that the assembly line has an integrated alarm screen that enables the monitoring of currently active alarms and the visualization of the machine's alarm history, it is an example of a smart manufacturing system and an industrial energy management system in the automotive industry.

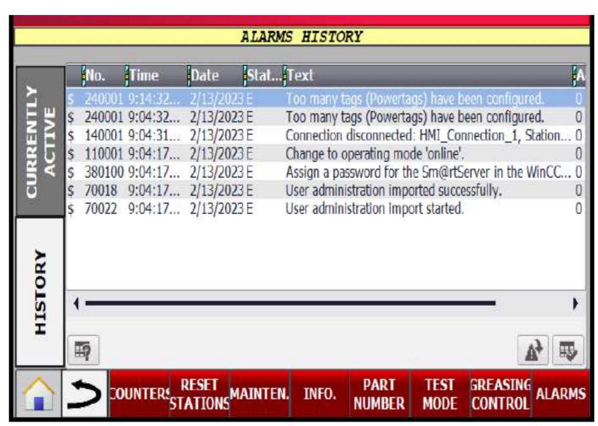

Fig. 3. The menu of alarms detection [26]

The assembly line has also put in place measures to prevent noise and vibration-related hazards. These measures are directly tied to the maximum allowed level, which is around 70 dB, and cannot be exceeded at the workplace without the use of safety precautions (such as insulation, helmets, etc.).

All that shown in Figures 1 to 3 demonstrates that the line is a flexible, smart line with an integrated energy management system [23, 24, 25]. Recipe Control, shown in Figure 4, allows the operator to select and manage the many parameter combinations to carry out a predetermined operation. Through its navigator button, users can access up to 200 recipe registries. A search option makes it simpler to look up a certain recipe.

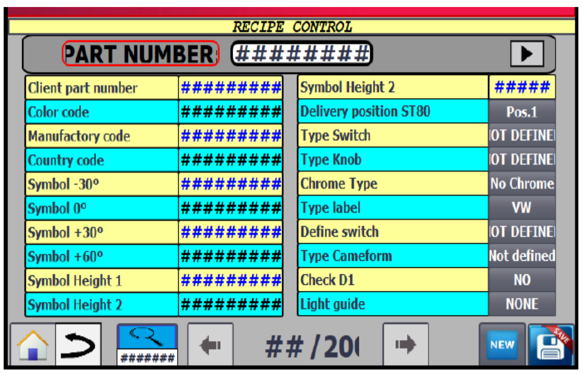

Fig. 4. The recipe menu [26]

The assembly line is a smart manufacturing system and with an included industrial energy management system because also it can control the times at each stage, timers allow the registry of different delays in each station. A model of a timer dedicated to each station can be observed in figure 5.

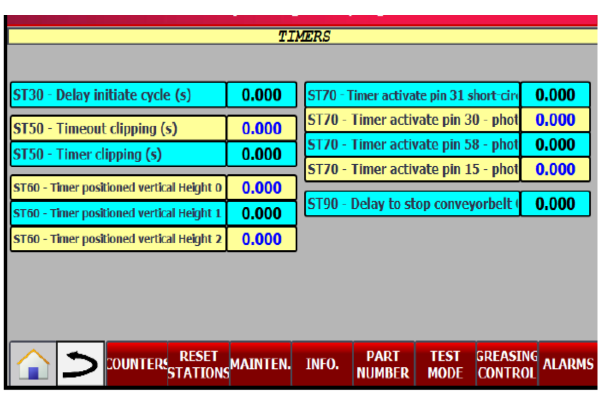

Fig. 5. The timers for each station [26]

This is important due to:

- Diverse Tasks Take Different Amounts of Time, certain assembly procedures require more time than others. Timers make sure that every station runs as efficiently as possible without causing the line to lag.
- Adaptive Workflow, timers can dynamically modify delays to avoid jams if a station notices an issue (such as a failure of the quality check).
- Synchronization, timers facilitate seamless handoffs between robots, machines, or human workers by assisting in the coordination of work between stations.
- Flexibility for Various Products, timers can modify delays according to the needs of each product if the assembly line produces a variety of product kinds.

In essence, timers increase the assembly line's productivity, flexibility, and responsiveness to demands.

4. CONCLUSIONS

A flexible, intelligent assembly line with an integrated industrial energy management system for the automotive industry. This concept aligns with Industry 4.0, integrating AI, IoT, and real-time data analytics to optimize production while reducing energy consumption.

A flexible, intelligent assembly line with energy management reduces costs, increases production, and has less environmental effects. Companies improve they're from:

- Enhanced effectiveness via real-time tuning.
- Reduced energy use and operating expenses because of intelligent energy management.
- enhanced flexibility in response to evolving production needs and product modifications.
- improved sustainability through a decrease in energy waste and carbon emissions.

A flexible, intelligent assembly line with energy management transforms automotive manufacturing into a smarter, more sustainable, and cost-effective operation.

Another conclusion is that Energy Audits & Continuous Improvement are needed related:

- ISO 50001 Compliance: Following international energy management system standards.

- Regular Energy Audits: Identifying inefficiencies and implementing corrective actions.
- Kaizen & Six Sigma for Energy Efficiency: Continuous process improvements to reduce energy waste.

Future research topics will include 5G-enabled smart factories, blockchain for energy transactions, and AI-powered predictive maintenance.

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[26] Procedura companie automotive – sisteme IMES

Sisteme de fabricație flexibile, inteligente și sisteme industriale de management al energiei în domeniul auto

Într-o ordine de idei, pentru a îmbunătăți productivitatea, durabilitatea și eficiența, industria auto pune din ce în ce mai mult accent pe producția inteligentă, producția flexibilă și sistemele industriale de gestionare a energiei. Două domenii importante de dezvoltare pentru a face față potențialului și provocărilor din această industrie sunt identificarea măsurilor de flexibilitate energetică și încorporarea tehnologiei moderne. Un sistem industrial de gestionare a energiei (IMES) conceput pentru a răspunde nevoilor specifice ale industriei automobilelor trebuie să aibă câteva elemente esențiale pentru gestionarea energiei în instalațiile de producție.

Cuvinte cheie: *Sisteme de fabricație flexibile, inteligente în domeniul auto, industria auto, sisteme industriale de management al energiei, productivitate energetică*

Demetrius PETRESCU (DUBIC), PhD, National University of Science and Technology POLITEHNICA Bucharest, Faculty of Industrial Engineering and Robotics, dubicdemetrius@yahoo.com.

Oana–Roxana CHIVU, PhD, Professor, National University of Science and Technology POLITEHNICA Bucharest, Faculty of Industrial Engineering and Robotics, virlan_oana@yahoo.co.uk.

Anamaria Ioana FEIER, PhD, Associate Professor, Politehnica University Timișoara, Materials and Manufacturing Engineering Department, anamaria.feier@upt.ro, 0040741111858.

Marilena GHEORGHE PhD, National University of Science and Technology POLITEHNICA Bucharest, Faculty of Industrial Engineering and Robotics, ghe.marilena@gmail.com.