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AI IN THE MANAGEMENT OF MECHATRONIC SYSTEMS: CURRENT DEVELOPMENTS AND FUTURE PERSPECTIVES

Emanuel Balc[1], Constantin Oprean[2,3], Doina Banciu[4] and Aurel Mihail Titu[5, 6]
[1] Lucian Blaga University of Sibiu, 10 Victoriei Street, Sibiu, România, 0009-0000-3546-7143, emybalc@yahoo.ro
[2] Lucian Blaga University of Sibiu, 10 Victoriei Street, Sibiu, România, 0000-0002-1710-0660, constantin.oprean@ulbsibiu.ro
[3] Academy of Romanian Scientists, 3 Ilfov Street, Bucharest, Romania
[4] Academy of Romanian Scientists, 3 Ilfov Street, Bucharest, Romania, banciu.doina@gmail.com
[5] Lucian Blaga University of Sibiu, 10 Victoriei Street, Sibiu, România, Corresponding author 0000-0002-0054-6535, mihail.titu@ulbsibiu.ro
[6] Academy of Romanian Scientists, 3 Ilfov Street, Bucharest, Romania

ABSTRACT: The paper analyses how artificial intelligence (AI) influences the management of mechatronic systems in the automotive industry, with a focus on technological news and future perspectives. The study starts from the need to integrate AI in all stages of the life cycle of modern vehicles, from design and production, to predictive maintenance and autonomous driving. Advanced AI features such as automated decision support, supply chain optimization, predictive analytics, and human-machine collaboration within Industry 5.0 are examined. Finally, strategic recommendations are formulated for a responsible and sustainable integration of AI in the management of automotive mechatronic systems, emphasizing the need for continuous training, interdisciplinary cooperation and adaptation to new regulations. The paper provides a clear vision of the transformative potential of AI in the automotive industry, positioning it as an essential element of future innovation.
KEYWORDS: Artificial Intelligence, Mechatronic Systems, Automotive Industry, Digital Management, Autonomous Vehicles

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1. INTRODUCTION

In recent decades, accelerated technological progress has led to an increasingly deep integration of artificial intelligence (AI) in various engineering fields, among which mechatronics stands out in particular – an interdisciplinary discipline that combines mechanics, electronics, automation and computer science. Amid this technological convergence, AI has become an essential tool not only in the design and operation of mechatronic systems, but also in their management and optimization from a managerial perspective.

Mechatronic systems management involves the effective coordination of the resources, processes, and technologies required to design, implement, monitor, and improve such complex systems. In this context, the role of AI is becoming increasingly prominent, as it enables data-driven decision-making, the automation of planning and control processes, as well as the forecasting of system performance in real time.

At present, AI is already being deployed in numerous mechatronic applications, from autonomous vehicles and industrial robots, to smart medical equipment and automated manufacturing systems. Machine learning algorithms, artificial neural networks, natural language processing (NLP), and image recognition are just a few of the AI technologies used to improve the performance and adaptability of these systems.

In modern manufacturing, for example, AI-powered mechatronic systems can monitor and adjust manufacturing process parameters in real time, thus reducing downtime, material waste, and operational costs. Collaborative robots (cobots) learn from interactions with human operators and adjust their behavior to work safely and efficiently in dynamic environments. At the same time, AI contributes to the predictive diagnosis of equipment, anticipating failures and scheduling preventive maintenance.

At the same time, the integration of AI into mechatronic systems brings a higher level of autonomy and self-optimization, essential characteristics in the context of Industry 4.0 and the transition to Industry 5.0, in which the focus is on personalization, sustainability and human-machine interaction. [1]

From a managerial perspective, AI plays a crucial role in strategic and operational decision-making. Managers often face complex challenges, such as optimizing the supply chain, allocating resources efficiently, minimizing risks, and ensuring consistent quality of products and services. AI provides valuable support through advanced data analytics, intelligent simulations, multi-objective optimizations and prediction-based decision support. [2]

For example, in the management of mechatronic system development projects, AI can help estimate durations and costs, identify potential bottlenecks, as well as recommend the most effective courses of action. In terms of operational management, AI allows real-time monitoring of system performance and proactive intervention in case of deviations from standards.

Another essential aspect is that of knowledge management. Intelligent systems can collect, structure and leverage information from multiple sources – from physical sensors, to historical databases and social networks – thus generating a knowledge base that supports organizational learning and continuous innovation.

Moreover, AI also contributes to the automation of decision-making, eliminating human error and reducing the time it takes to make complex decisions. In this regard, the use of AI-based Decision Support Systems (DSS) stands out, which can suggest the best options depending on the defined objectives and the operational context. [3]

Going forward, the role of AI in the management of mechatronic systems is expected to continue to evolve as technologies become more accessible and the volume of data increases exponentially. One of the major directions will be the development of autonomous management systems, capable of self-configuring, self-optimizing and learning from experience.

Integrating AI into mechatronic systems management is no longer an option, but a necessity for organizations that want to remain competitive in a dynamic and technological environment. By adopting these technologies, significant benefits can be achieved in terms of efficiency, quality, adaptability and innovation – key elements for long-term success in the digital age.

2. THEORETICAL AND TECHNOLOGICAL FOUNDATIONS

In the contemporary automotive industry, mechatronic systems represent the technological foundation of modern vehicles, constituting a complex intersection between mechanics, electronics, informatics and automatic control. These systems are found in most of a car's critical functions, from assisted braking systems (ABS), traction and stability control (ESC), to electric power steering and emerging technologies such as autonomous and electric vehicles. The integration of mechatronic components has led to the emergence of a new generation of intelligent vehicles, capable of perceiving the environment, making real-time decisions and interacting with drivers and road infrastructure. For example, automated parking systems use ultrasonic sensors and video cameras coordinated by Electronic Control Units (ECUs), while autonomous vehicles rely on convolutional neural networks that process images from multiple cameras to detect obstacles and plan the optimal route.

The basic components of these systems include mechanical elements – such as active suspension, automatic transmission or variable jet steering – interconnected with sensors (accelerometers, gyroscopes, LIDAR sensors, radar), actuators (electric motors, electromagnets), and electronic control units that process signals and generate precise commands. Software control algorithms integrate this data to ensure predictable and safe behavior.

At the base of artificial intelligence (AI) used in the automotive field are several technological paradigms, the most important of which are machine learning (ML) and deep learning (DL). ML allows systems to extract models from historical data and make predictions – for example, anticipating the need for an overhaul based on vehicle behavior and road conditions. Deep learning, on the other hand, enables complex image recognition and interpretation of signals from video cameras for autonomous driving. In addition, recurrent neural networks (RNNs) are used to interpret timelines, which are essential for analysing driver behavior or surrounding traffic. Expert systems, based on pre-established rules, are integrated into assisted diagnosis and maintenance systems. [4]

The architecture of a modern vehicle can comprise more than 100 ECU units, organized in distributed networks and connected through communication protocols such as CAN, LIN, FlexRay or Automotive Ethernet. Fast communication between these units is essential for the integrated operation of mechatronic systems. In parallel, cloud connectivity allows vehicles to benefit from over-the-air updates, real-time data collection and analysis, as well as digital twin functionalities. They are used to create a virtual replica of the vehicle and simulate different operating scenarios, thus improving the development and maintenance process. [5]

Industry data shows an exponential increase in the use of AI in the development of automotive systems. Trend graphs indicate a steady increase in the complexity of vehicle electronic architecture, in parallel with a decrease in development time due to AI simulations and virtual testing. Therefore, understanding these technological fundamentals is essential for any analysis of the modern management of mechatronic systems in the automotive industry.

3. MANAGEMENT OF MECHATRONIC SYSTEMS

The management of mechatronic systems in the automotive industry involves a strategic and integrated approach to complex processes involving both technical and organizational aspects. In a sector that is undergoing continuous technological transformation, such as the automotive sector, the challenges related to the integration of mechanical, electronic and software systems must be managed effectively to ensure performance, safety and innovation. A relevant example is the development process of electric and autonomous vehicles, which requires the coordination of mechanical engineering, software, control, industrial design and testing teams, under an agile and interdisciplinary managerial leadership.

One of the main components of this management is the supervision of the life cycle of mechatronic systems, from concept and design, to testing, production, use and decommissioning. This process is supported by digital PLM (Product Lifecycle Management) platforms, which integrate technical data and workflows between different departments, reducing development times and avoiding integration errors. [6]

In addition, effective management involves the use of risk analysis techniques, especially in the context of functional safety. The ISO 26262 standard regulates safety processes in the development of automotive electrical and electronic systems, and compliance with this standard becomes a major managerial responsibility. Any failure in critical systems – such as brakes, steering or assistance systems – can have serious consequences, requiring strict monitoring of all stages of development.

At the same time, the transition from traditional waterfall management models to Agile methodologies stands out, which allow the incremental delivery of functionalities and rapid adaptation to market requirements, as can be seen in figure 1.

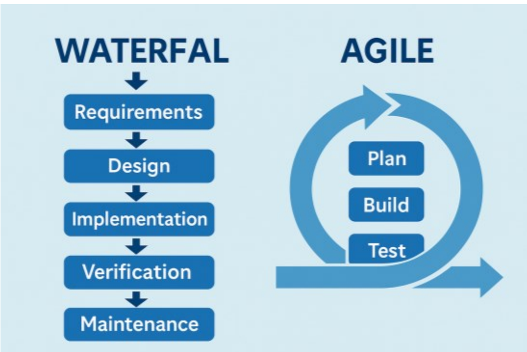

Figure 1. Waterfall vs. Agile: A visual comparison

In the context of the development of in-car software, teams use sprints, backlogs and continuous testing to implement control algorithms or autonomous driving functions.

In addition to engineering aspects, mechatronic systems management also includes logistical, financial and human resources dimensions. Coordinating the global supply chain, collaborating with hundreds of component suppliers, and integrating new technologies into production lines requires rigorous planning and the ability to adapt to rapid market changes. The COVID-19 pandemic and the global semiconductor crisis have demonstrated how vulnerable these supply chains can be and how important it is to digitize operational management.

The management of mechatronic systems in the automotive industry is a complex, multi-dimensional process that requires a strategic vision, a deep technological understanding and a capacity for cross-functional coordination. Success in this area depends on the ability to integrate emerging technologies, respond quickly to market challenges, and effectively manage resources and risks, in an increasingly digitized and globally connected ecosystem.

4. THE ROLE OF ARTIFICIAL INTELLIGENCE IN THE MANAGEMENT OF MECHATRONIC SYSTEMS

Artificial intelligence (AI) has become a strategic tool in fundamentally transforming the way mechatronic systems are managed in the automotive industry. This technological integration is not just about automating production processes or controlling autonomous vehicles, but is redefining decision-making within automotive organizations, with a focus on efficiency, predictability and adaptability. Today, managers are increasingly relying on data generated by vehicles, sensors, and the supply chain to make real-time decisions based on advanced machine learning and predictive analytics algorithms.

One of the most important benefits of AI in automotive management is its ability to automate decisions. Instead of decisions made intuitively or through classic analysis methods, AI algorithms process huge volumes of operational, logistical, and vehicle usage data to provide concrete recommendations or even make autonomous decisions. For example, in production management, AI can analyse workflows in real-time to identify bottlenecks or inefficiencies, and reconfigure production lines to maintain optimal productivity. Reinforcement learning algorithms can also learn from previous results to continuously improve system performance. [7]

A notable example is AI-based Decision Support Systems (DSS) used in predictive vehicle maintenance. These systems collect and analyse data from sensors mounted on critical vehicle components – such as the engine, transmission or braking system – and, based on predictive models, can predict defects weeks before they occur. [8]

AI also helps optimize the supply chain, a crucial aspect in the context of globalization and the increasing complexity of automotive components. By integrating AI into ERP (Enterprise Resource Planning) systems, automotive companies can monitor component availability in real-time, predict delays, and adjust orders or delivery routes to avoid bottlenecks. For example, Toyota uses AI algorithms to analyse weather, geopolitical, and economic data, anticipating potential risks in the supply chain and acting proactively.

The impact of AI in this context can also be highlighted visually through a graph that compares predictive maintenance vs. reactive maintenance efficiency. The data indicates a reduction of up to 30% in maintenance costs and a 40% increase in vehicle uptime when using AI for preventive maintenance, as can be seen in figure 2.

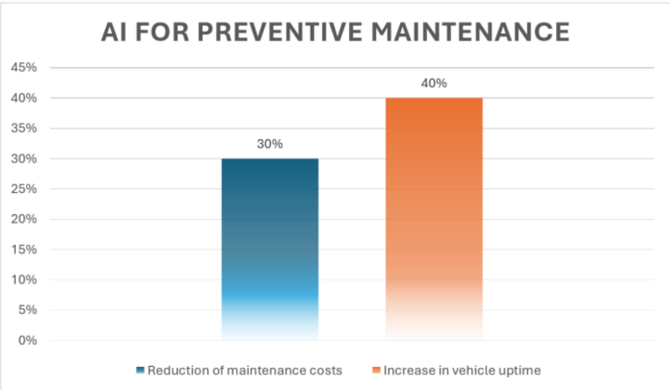

Figure 2. The Impact of AI in preventive maintenance

Also, managerial reaction time to critical events can be significantly reduced – from hours to minutes – thanks to automatically generated intelligent alerts.

Therefore, AI not only supports but also profoundly transforms the management of mechatronic systems in the automotive industry. It creates a more transparent, faster and more adaptable decision-making framework, allowing companies to proactively respond to market changes and consumer needs. In the near future, the role of AI is expected to become even more central, evolving from a simple decision support tool to a cognitive partner that will collaborate in real time with human decision-makers, generating innovative and sustainable solutions.

5. PERSPECTIVES AND FUTURE TRENDS

Looking to the future, the integration of artificial intelligence into the management of mechatronic systems in the automotive industry promises to become even more profound, bringing with it a series of major transformations that will redefine not only the way vehicles are built and operated, but also the way businesses in this sector are conducted. One of the most important directions is the development of autonomous management, in which AI-based systems not only assist managerial decisions, but end up taking them over completely, in certain well-defined contexts. This type of autonomy will allow the real-time optimization of production, maintenance or logistics processes, without human intervention, based on algorithms that continuously learn from operational data.

A growing trend in mechatronic design is the use of generative AI to automatically create optimized automotive components based on weight, strength, cost, and sustainability. Companies like General Motors and Autodesk use this approach with 3D printing to cut development time and materials. AI is also merging with IoT, blockchain, and digital twin technologies to enable smart, self-regulating systems. Digital twins simulate real-time changes without affecting physical assets, while blockchain ensures secure, traceable sensor data. These integrations support Industry 5.0, which emphasizes human-machine collaboration, customization, and sustainability. Here, AI acts not just as a tool but as a cognitive partner aiding complex decisions.

Statistical data support these trends. According to a report published in 2024, more than 70% of global automakers plan to integrate generative AI into design processes by 2027, and 85% are already investing in digital twin and IoT technologies to fully digitize their production lines. These investments are justified not only by the need for innovation, but also by competitiveness pressures and increasingly stringent sustainability and safety regulations.

The future of mechatronic systems management in the automotive industry will be defined by autonomy, human-machine collaboration and intelligent data integration. Artificial intelligence will evolve from a simple analytical tool to an active actor in the decision-making process, capable of understanding, learning and acting responsibly. The challenges will be manifold, but the benefits – in terms of efficiency, innovation and adaptability – will make AI an indispensable component of any future automotive business model.

6. CONCLUSIONS AND RECOMMENDATIONS

The present paper explored in depth how artificial intelligence influences the management of mechatronic systems in the automotive industry, highlighting both the current state of the technologies involved and the future prospects. Modern mechatronic systems can no longer be designed without a deep integration of intelligent components, and the management of these systems requires an interdisciplinary, adaptive and data-driven approach. The automotive industry is in the midst of digital transformation, and AI plays a fundamental role in this evolution, intervening in all stages of the product lifecycle: from design and production, to maintenance and user interaction.

AI's contribution to this area is significant through the automation of decision-making processes, the optimization of supply chains, predictive diagnostics, product personalization, and the creation of connected ecosystems.

In terms of perspectives, a shift towards autonomous systems management is foreshadowed, in which AI becomes not just a tool, but a cognitive collaborator capable of acting in real time and learning continuously. Industry 5.0 will encourage human-machine collaboration, and AI will have to be developed and implemented with responsibility, transparency and respect for human values.

Based on these conclusions, several strategic recommendations emerge. Automotive companies should invest in developing employees' digital skills through ongoing training in AI, data science, ethics, and cybersecurity. Collaboration between manufacturers, suppliers, and researchers is crucial to create shared standards and interoperable solutions. Finally, AI should be implemented within a clear ethical and legal framework to ensure user protection and promote responsible innovation.

Finally, we can say that artificial intelligence represents a major opportunity for reinventing management in the automotive industry. Companies that understand the transformative potential of these technologies and act strategically towards their integration will have a significant competitive advantage in the economy of the future. Therefore, AI is not just a technological trend, but a fundamental direction of development that redefines the very nature of the vehicle and the processes that support it.

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