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SPECIFIC METHODS IN THE AUTOMOTIVE INDUSTRY: ARTIFICIAL INTELLIGENCE IN THE INTEGRATION OF NONCONVENTIONAL MECHATRONIC SYSTEMS

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ABSTRACT: The present paper aims to analyze the nonconventional use of artificial intelligence (AI) in optimizing classical and modern methodologies in the automotive industry, focusing on the Waterfall model, the Just in Time (JIT) concept and Agile methodologies. AI fundamentally transforms these traditional approaches, thus responding to the need for flexibility, efficiency and adaptability in an industry in full technological evolution. In this context, methodologies such as Extreme Programming (XP), Scrum and Kanban are reviewed and adapted through the nonconventional use of AI, optimizing development processes and the integration of mechatronic systems. The paper also explores how AI improves the Waterfall model and JIT flows, providing advanced solutions for automating and streamlining production. Industry examples such as Tesla, Toyota, and Volkswagen illustrate the real impact of AI in reducing costs, increasing speed of execution, and adapting to dynamic market demands. The paper concludes that AI, through nonconventional uses, opens up new perspectives for innovation in the development of vehicles and mechatronic systems.
KEYWORDS: Artificial intelligence, Nonconventional mechatronic systems, Agile and Waterfall models, Just in Time, Automotive industry.

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1. INTRODUCTION

The automotive industry is undergoing a significant digital transformation, and the adoption of advanced technologies is becoming a central factor in the design, development and integration processes of mechatronic systems. In this context, artificial intelligence (AI) is playing an increasingly important role, bringing fundamental changes both in production processes and in the optimization and design of complex systems. The nonconventional use of AI in the integration of mechatronic systems represents a new direction that offers innovative solutions to traditional industry challenges. In addition to AI, techniques and working methods such as Agile, Extreme Programming (XP), Scrum, Kanban, Just in Time and the Waterfall model have a crucial role in coordinating and streamlining development processes. These methodologies not only optimize workflows, but, integrated with AI, contribute to improving the performance of mechatronic systems in vehicles.

Mechatronic systems, which integrate mechanical, electronic and IT components, are essential for the modern automotive industry. From brake control systems to advanced driver assistance systems (ADAS), mechatronics defines vehicle functionality and safety. As cars become more intelligent and autonomous, the requirements for these systems have increased significantly, both in terms of performance and complexity.

AI brings a new dimension to these systems, allowing them to learn and adapt to various driving conditions and scenarios. Traditionally, mechatronic systems were designed to follow strict rules and rigid algorithms. By integrating AI, these systems can now use machine learning techniques and pattern recognition algorithms, thus becoming able to optimize vehicle operation in real time.

Using AI in these systems is not a simple or linear process. In an industry known for rigid standards and traditional development methods, the adoption of nonconventional techniques becomes essential. For example, AI can be used in the testing phase of mechatronic systems to anticipate potential failures or generate alternative solutions, thereby reducing the time and costs associated with manual testing.

One of the main concepts that has gained popularity in software development is the Agile methodology, which emphasizes flexibility, collaboration, and continuous feedback. [1]

This is ideal for a dynamic industry such as the automotive industry, where iterative product

development allows for rapid adjustments according to changing requirements and new technical challenges.

In the automotive industry, Agile is used in an nonconventional way for the integration of AI and mechatronic systems. Engineering teams can develop and adjust AI algorithms in real-time, within rapid feedback and testing cycles, reducing the risks associated with launching new functionalities and providing better customization of the final product.

For example, in the case of testing and integrating AI into Automatic Emergency Braking Systems, teams can develop initial prototypes of AI algorithms, test them in real-world traffic scenarios, and make adjustments based on the feedback received. This iterative process ensures continuous improvement and greater adaptability of the system to various road situations.

Directly related to Agile, Extreme Programming (XP) is a methodology that emphasizes intense collaboration between team members and frequent product deliveries. [2]

In the automotive industry, where systems are highly complex and interdependent, XP is proving effective in managing the rapid development and integration of AI in mechatronics. The constant feedback and continuous improvements offered by XP allow for rapid adaptation to new technological requirements and changes in industry regulations.

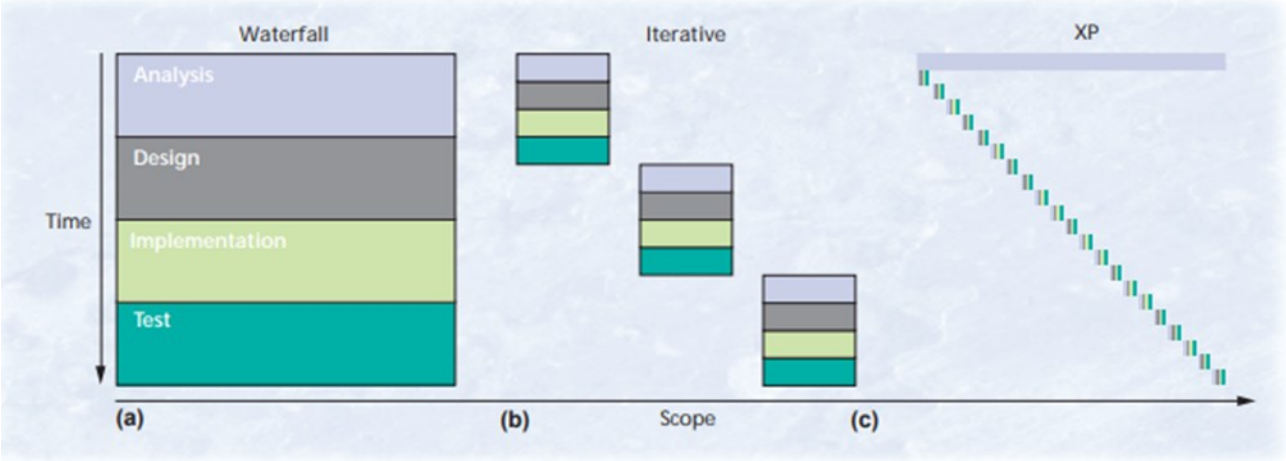

Figure 1. The XP model

In Figure 1, the differences between the iterative approach, the Waterfall model, and the XP (Extreme Programming) method are shown. This is also illustrated in Figure 2.

Commonsense	XP extreme	XP implementation practice
Code reviews	Review code all the time	Pair programming
Testing	Test all the time, even by customers	Unit testing, functional testing
Design	Make design part of everybody's daily business	Refactoring
Simplicity	Always work with the simplest design that supports the system's current functionality	The simplest thing that could possibly work
Architecture	Everybody works to refine the architecture all the time	Metaphor
Integration testing	Integrate and test several times a day	Continuous integration
Short iterations	Make iterations extremely short—seconds, minutes, and hours rather than weeks, months, and years	Planning game

Figure 2. Differences between the practices of the traditional AGILE method and the XP method

Another essential aspect of XP is continuous testing, which ensures the proper functioning of integrated AI systems. Similarly, Scrum, another popular agile methodology, is used to organize projects into short and intense sprints, each with the goal of producing a working version of an improved mechatronic system. [3]

In the automotive industry, Scrum ensures the effective coordination of multidisciplinary teams collaborating to develop and integrate AI into vehicles.

The Kanban technique, which originated in Japanese industry, is used to manage and optimize workflows. [4]

In the development of mechatronic systems, Kanban helps teams visualize and track the progress of tasks in real-time, ensuring that all stages of the process are carried out in an efficient and organized way. When

combined with AI, this technique becomes even more powerful. AI algorithms can predict delays or bottlenecks in the development chain and propose automated optimization solutions.

For example, in the development of sensor systems for autonomous vehicles, Kanban allows monitoring of the entire development lifecycle, from prototyping to final implementation. AI algorithms integrated into this process can identify failures in prototypes and propose solutions faster than conventional methods, thus reducing risks and delays.

Although Agile methods have gained a lot of ground in recent years, traditional concepts such as "Just in Time" and the Waterfall model continue to be relevant in the automotive industry. "Just in Time" (JIT), a production management technique that emphasizes minimizing inventory and reducing waste, can be improved through AI to optimize logistics and supply processes. AI algorithms can predict the demand for parts and materials, thus ensuring that mechatronic production is as efficient as possible. [5]

On the other hand, the Waterfall model, a traditional linear development methodology, can be enhanced with AI to optimize planning and design stages. In an nonconventional approach, AI can generate virtual prototypes of mechatronic systems, speeding up the passage through the development phases and reducing the time required to test and deploy systems.

Nonconventional methods, together with traditional approaches, open up new perspectives and innovative solutions to the increasingly complex challenges in this field.

2. INTEGRATING AGILE METHODOLOGIES IN THE AUTOMOTIVE INDUSTRY: NONCONVENTIONAL USE OF ARTIFICIAL INTELLIGENCE FOR MECHATRONIC SYSTEMS OPTIMIZATION

The automotive industry is in a period of rapid technological change, in which the complexity of mechatronic systems and the growing demands of the market require the adoption of agile and flexible approaches in development processes. In this context, Agile methodologies, together with artificial intelligence (AI), have a significant impact on the optimization of mechatronic systems. Agile is a model that promotes collaboration, adaptability, and continuous delivery, all of which are necessary in an industry where technological changes are frequent and rapid.

The Agile concept, originally designed for software development, was quickly adopted in other areas due to its flexibility. [6]

In the automotive industry, where the requirements for innovation and efficiency are extremely high, Agile has become a popular solution to meet the needs of integrating AI into mechatronic systems.

Agile is based on an iterative and incremental process, which allows development teams to deliver functional parts of the system frequently. Instead of a traditional approach, such as the Waterfall model, where all stages must be fully completed before moving on to the next, Agile allows for continuous adaptation to changing customer and market requirements. This is crucial in the development of mechatronic systems, where AI plays a significant role in optimizing the functionality and performance of complex components, such as automatic braking systems or stability control systems.

A notable example of the use of Agile in the development of mechatronic systems can be seen at Tesla, the company that uses AI to continuously optimize the performance of its electric vehicles. In the development process, Tesla's engineering teams use short sprints and frequent iterations to test and improve AI algorithms that control critical functions, such as autopilot. The feedback received from users is constantly integrated, allowing rapid adjustment of system parameters and continuous improvement of performance.

Extreme Programming (XP) is one of the most popular Agile methods, known for its intense application of the principles of rapid iteration and constant feedback. In the development of mechatronic systems in the automotive industry, XP is particularly useful for managing the complexity of AI algorithms that need to be continuously integrated and optimized.

The XP methodology includes practices such as continuous testing and frequent releases of functional releases. They are essential in the development of mechatronic systems in which AI plays a critical role. Machine learning algorithms, which are often integrated into autonomous vehicles and driver assistance systems, require constant adjustments and improvements based on real-world data. XP facilitates this approach by allowing teams to quickly implement changes and get feedback from users or simulated environments.

A practical example of the XP methodology in the automotive industry is provided by BMW, which uses this method for the continuous development and

optimization of AI algorithms in its autonomous vehicles. Using XP, BMW development teams can quickly implement new AI functions, test their performance in real conditions and immediately adjust solutions based on the feedback received. This approach allows BMW to remain competitive and deliver frequent and efficient improvements to its mechatronic systems.

Scrum is an Agile methodology that is based on intense collaboration between development, production and management teams. [7]

In the automotive industry, where mechatronic systems are highly complex and require close cooperation between hardware and software engineers, Scrum facilitates this collaboration through its structure organized in sprints and regular meetings.

Scrum promotes transparency, constant feedback, and rapid adaptation, as can be seen in figure 3, all of which are essential in the development of AI-integrated mechatronic systems. In a Scrum project, development teams set clear goals for each sprint, test the results, and receive immediate feedback from all parties involved. This enables continuous improvement of mechatronic systems, especially where AI is used to optimise and automate vehicle functions.

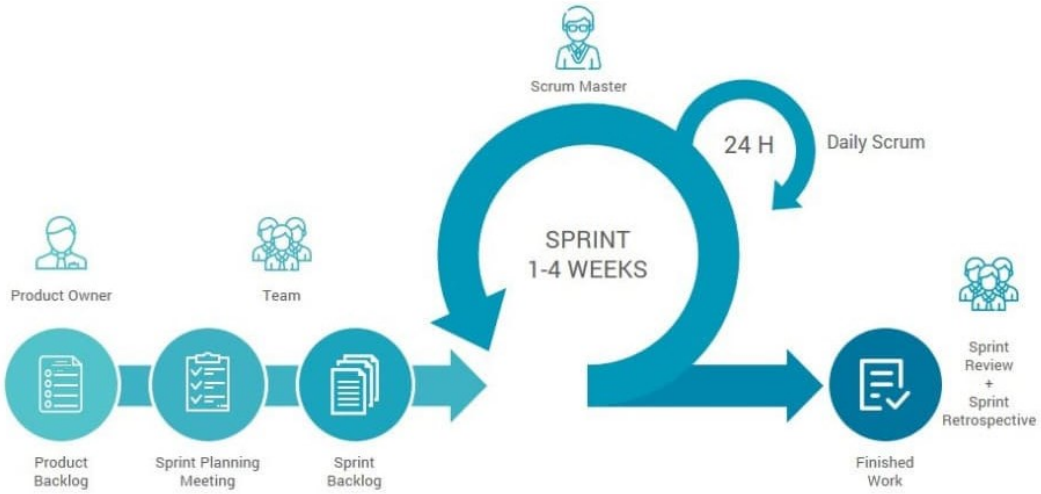

Figure 3. The Scrum process

An example of the effective use of Scrum in the automotive industry is the implementation at Volvo Cars. The company has adopted Scrum for the development of its autonomous driving systems, which rely on AI algorithms to analyze the environment and make quick decisions. Volvo's Scrum teams work closely with each other to deliver functional versions of the system, which are then tested and improved based on the results. This approach has enabled Volvo to make rapid progress in the development of autonomous driving technologies, responding promptly to customer requirements and feedback.

Kanban is another Agile methodology that focuses on visualizing processes and optimizing workflow. [8] In the automotive industry, where integrating AI into mechatronic systems involves managing a large number of complex and interdependent tasks, Kanban offers a clear way to track progress and identify bottlenecks.

By using Kanban boards, development teams can visualize every step of the process, from research and development to testing and implementation. This allows for better planning and coordination of resources, as well as a quick reaction to any problems that arise during development. In the case of AI, Kanban facilitates an nonconventional approach to algorithm development, allowing teams to adjust tasks based on algorithm performance in simulated or real-world environments. Toyota, the pioneer of the Kanban concept, uses this methodology in the development of AI for its hybrid and autonomous vehicles. Kanban helps Toyota manage the continuous stream of mechatronic system improvements, ensuring that every task is completed on time and that development teams have a clear picture of the overall progress. This approach helps reduce development times and deliver high-quality AI solutions.

A relevant example of the nonconventional integration of AI into Agile processes comes from Audi, which has combined Agile methodologies with the intensive use of AI in the development of its electric drive systems. Audi took an iterative approach, using Agile sprints to test AI algorithms

that control the electric motor's performance and energy efficiency.

An nonconventional element of Audi's approach is the use of AI to adjust engine performance settings in real-time based on traffic conditions and the user's driving style. Instead of following a rigid and linear development process, Audi implements frequent changes in AI algorithms, testing performance in simulated and real-world environments and quickly adjusting parameters based on feedback received.

This iterative process has enabled Audi to develop a highly efficient electric powertrain that responds promptly to market demands and technological changes while maintaining its competitiveness.

The integration of Agile methodologies in the automotive industry, together with the nonconventional use of AI, represents an innovative solution for optimizing mechatronic systems. Agile methods such as Extreme Programming, Scrum, and Kanban enable teams to collaborate effectively, quickly adapt AI solutions to changing requirements, and deliver continuous improvements in real-time. Industry case studies demonstrate the positive impact of these methodologies on the performance of AI-integrated vehicles and mechatronic systems. Thus, Agile becomes an essential approach in the development of cutting-edge technologies in the automotive industry.

3. THE "JUST IN TIME" CONCEPT AND THE WATERFALL MODEL: CLASSIC AND NONCONVENTIONAL APPROACHES WITH ARTIFICIAL INTELLIGENCE IN THE AUTOMOTIVE INDUSTRY

The automotive industry has adopted several methodologies and concepts over time to optimize production and product development. Two of these classic approaches, the Waterfall model and the Just in Time (JIT) concept, have had a major impact on how organizations have managed complex projects and supply chains. However, in the context of technological advancement and the increased use of artificial intelligence (AI), these approaches have been reinvented and improved to meet modern needs.

The Waterfall model, also known as the waterfall model, was first introduced by Dr. Winston W. Royce in 1970 in his article "Managing the Development of Large Software Systems". It was designed to provide a clear and sequential structure for the development of software and systems, and was later adopted in other areas, including the automotive industry. The basic principles of this model focus on development in well-defined and successive stages: analysis, design, implementation, testing and maintenance. [9]

One of the main advantages of the Waterfall model is its clarity and predictability. Each stage must be completed before the next begins, which provides a rigid structure and well-determined planning. However, this linear approach has significant drawbacks in the context of the increased need for flexibility and adaptability in modern industry, where AI plays a crucial role in optimizing and innovating mechatronic systems.

One of the limitations is the rigidity of the model: Waterfall does not allow going back to previous stages to correct errors or adapt solutions based on feedback received in later stages. [10] This is problematic in situations where requirements change or are difficult to define from the start. Another limitation is the lack of flexibility: In the development of advanced mechatronic systems, such as those used in autonomous vehicles, frequent changes in requirements and the rapid evolution of technologies require more flexible methods, such as those offered by Agile or AI.

One challenge that arises is the nonconventional integration of AI into the Waterfall model: In the modern context, AI is used to address many of the limitations of the Waterfall model. An example of nonconventional integration is the use of AI algorithms to support the analysis and planning processes in the early stages of the Waterfall model. AI can automate requirements analysis and effectively identify potential risks and issues before starting the implementation phase.

A concrete example is the use of AI at Volkswagen, where the Waterfall model is combined with AI to speed up the design phase of new vehicles. Machine learning algorithms are used to analyze data from previous models, identifying patterns and proposing optimized solutions for new models. This allows you to reduce planning time and the risk of errors in later stages.

Another way AI improves the Waterfall model is in the testing stage. Instead of testing being just a final stage, AI allows automated testing to be integrated throughout each stage of development. For example, AI-based testing systems can continuously analyze the performance of mechatronic prototypes and detect errors earlier, thus reducing the time and cost required to correct problems.

The Just in Time (JIT) concept, as can be seen in figure 4, was first introduced by Toyota in the 1970s, being one of the pillars of Toyota's production

method. JIT's main goal is to reduce waste and optimize the production flow by delivering exactly the required amount of components at the right time, without unnecessary inventory. [11]

This allows for reduced storage costs and improved overall production efficiency. However, the modern challenges of the automotive industry, such as fluctuations in demand, the complexity of supply chains, and the need for product customization, have led to the need to improve the JIT concept. [12]

AI is playing a key role in this transformation, enabling the implementation of nonconventional solutions to optimize supply chain and production in real-time.

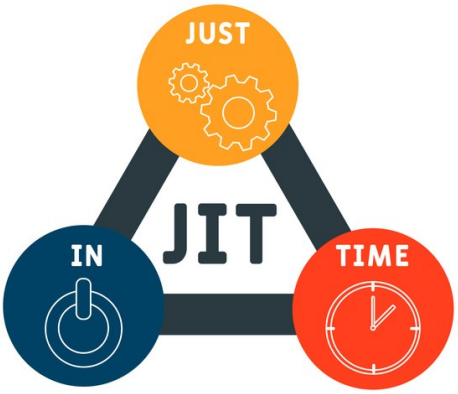

Figure 4. Just In Time concept

One of the most notable examples of integrating AI into JIT systems also comes from Toyota. Through the use of AI and machine learning algorithms, the company has been able to improve its ability to forecast demand and manage inventory. AI analyzes historical and current sales data, along with other external variables such as economic conditions and market trends, to predict component demand with much greater accuracy.

Additionally, AI enables real-time monitoring of production and deliveries, identifying any discrepancies or delays, and automatically adjusting production flows to avoid accumulating unnecessary inventory. This integration of AI into the JIT concept has led to a significant reduction in delivery times and increased efficiency in supply chains.

Practical example – Tesla and JIT management with AI: Tesla, an innovation leader in the automotive industry, has implemented AI to optimize JIT flows within its EV production. The company uses AI to track every component and subassembly in the production process, optimizing deliveries and production according to dynamic market requirements. For example, Tesla uses AI algorithms to adjust production based on orders recorded in real-time, thus minimizing inventory and eliminating waste.

This nonconventional approach to JIT has allowed Tesla to manage large fluctuations in demand and deliver custom vehicles in a short time. Through real-time analysis of production data and demand, AI allows the company to quickly adjust manufacturing processes to respond effectively to market demands.

Integrating AI into the JIT concept not only improves supply chain efficiency, but also contributes to increased flexibility and reduced production costs. A clear example of the use of AI within JIT to optimize production performance is Ford, which has adopted an advanced AI-assisted production management system. Ford has implemented an AI system that can monitor every stage of production, analyzing material and stock flows in real time. AI algorithms detect any deviations from the original plan, automatically adjusting production to ensure that only the necessary components are produced and delivered on time. This not only improves efficiency, but also significantly reduces the waste of materials and resources.

There are several advantages to using AI in optimizing the JIT concept:

Reduction of errors: Through real-time monitoring and automatic adjustment of production flows, AI can reduce human errors and delays in deliveries.

Increased efficiency: AI can optimize the use of resources, ensuring that production is done only when needed, thus reducing storage and transportation costs.

Increased adaptability: By using machine learning algorithms, AI can predict fluctuations in demand and quickly adjust production processes according to market needs.

In the end, both the Waterfall model and the JIT concept have been significantly improved through the use of AI, providing innovative solutions to modern challenges in the automotive industry. While the Waterfall model continues to be relevant for its clear structure and predictability, AI integration allows for a greater degree of flexibility and efficiency, especially in the analysis and testing phases. On the other hand, the JIT concept, with the help of AI, has strengthened its position as a central pillar of modern manufacturing, providing an optimized solution for supply chains and manufacturing processes.

Thus, the nonconventional use of AI in these traditional approaches opens up new opportunities for innovation in the automotive industry, helping to

increase competitiveness and develop sustainable and efficient solutions for the future.

4. CONCLUSIONS

The automotive industry is going through a period of profound transformations, characterized by an increasing integration of advanced technologies, especially artificial intelligence (AI), in development and production processes. In this context, classic and modern methodologies, such as the Waterfall model and the Just in Time (JIT) concept, have been reinvented and adapted to meet new market demands and harness the potential offered by AI.

The use of the Agile methodology has become essential in the automotive industry, especially due to its flexibility and ability to respond quickly to changes in customer requirements and technological developments. AI, combined with Agile, enables development teams to deliver continuous improvements and optimize the performance of mechatronic systems through iterative testing and rapid adjustments.

Companies like Tesla and BMW have successfully demonstrated how AI-assisted Agile can optimize development processes. They use frequent sprints to test and improve AI algorithms embedded in vehicles, thereby reducing development times and costs associated with errors. The collaboration between the software and hardware teams, facilitated by Agile methodologies, allows for more efficient integration of AI into vehicles and rapid adaptation to market needs.

The Waterfall model, while sometimes considered rigid, remains a popular approach in many industries, including automotive, due to its clarity and phased structure. However, this classic model has been significantly improved by the integration of AI, which allows it to overcome some of its traditional limitations. AI makes it easy to automate and optimize the initial phases of development, such as requirements analysis and planning, which reduces the risk of errors in later stages of the project.

Volkswagen's case study illustrates this nonconventional integration, where AI is used to speed up design processes and propose optimized solutions based on data analyzed from previous projects. This use of AI in the Waterfall model allows for greater flexibility, even in a rigid sequential framework, giving automotive organizations the ability to respond faster and more effectively to changes in project requirements.

The Just in Time (JIT) concept has been a pioneer in optimizing the supply chain and reducing unnecessary inventory within the automotive industry. In the modern era, AI has radically transformed this concept, bringing a new dimension of efficiency and flexibility. AI can analyze historical and real-time data to predict demand and adjust production and supply flows in an accurate and adaptable way. The examples from Toyota and Tesla highlight the significant impact of AI on JIT. By using machine learning algorithms and predictive analytics, these companies have been able to improve their ability to optimally manage inventory and reduce waste. AI enables constant monitoring of supply and production chains, providing the ability to adjust workflows in real-time to respond to fluctuations in demand, thereby reducing costs and increasing overall efficiency.

What emerges from the discussion of the Waterfall model and the JIT concept is that AI not only complements them, but also transforms them, providing a new perspective on how these methodologies can be used in the digital age. Both Waterfall and JIT are examples of classic approaches that have been significantly improved by integrating AI, allowing for greater adaptability, efficiency, and cost reduction.

As the automotive industry becomes increasingly complex and connected to emerging technologies such as AI and autonomous vehicles, the use of methodologies that integrate these technologies becomes essential. AI not only optimizes development and production processes, but also redefines the way projects are approached, providing unprecedented flexibility within methodologies previously considered rigid.

In conclusion, AI has managed to transform classic and modern methodologies in the automotive industry, such as the Waterfall model and the JIT concept, bringing significant innovations and opening up new opportunities for process optimization. The integration of AI into Agile methodologies has allowed for a more flexible and faster development of mechatronic systems, and the use of AI within classical approaches such as Waterfall and JIT has brought a degree of efficiency and adaptability essential to the modern world.

In the future, the role of AI in the automotive industry will become increasingly important, influencing both the production of vehicles and the way they are developed and optimized. Organizations that manage to combine classic approaches with new emerging technologies will be the ones that will be able to

remain competitive and lead the transformations in the industry. AI is not just an optimization tool, but a catalyst for innovation, capable of redefining the boundaries of technology and the automotive industry.

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