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DEVELOPMENT OF HYBRID INTELLIGENT SYSTEMS FOR DECISION SUPPORT IN COMPLEX SOFTWARE PROJECTS

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Abstract. *In today's world, where the complexity of software projects is constantly increasing, the development of hybrid intelligent systems for decision support is becoming extremely relevant. This research presents novel models and methods aimed at enhancing the decision-making process in complex software projects. A hybrid intelligent decision support system was developed by integrating agent-based modeling, data-driven analytics, and agile project management principles. It has been shown that the proposed system improves decision accuracy by 18% and reduces project-related risks by 22% compared to conventional project management approaches. New algorithms for decision-making under uncertainty and complexity were developed and tested in simulated environments. The results obtained demonstrate the adaptability and effectiveness of the hybrid approach in dynamic project conditions. It was also established that combining artificial intelligence techniques with traditional methodologies enables faster response to changes in requirements and technology. Hence, the study confirms the feasibility and efficiency of hybrid intelligent systems in supporting managerial decisions throughout the entire software project lifecycle. The findings can be applied to improve project planning, risk mitigation, and overall project quality. This research contributes to the theoretical and practical advancement of decision support systems in the field of software engineering.*

Key words: *hybrid intelligent systems, decision support, complex software projects, artificial intelligence, method integration.*

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1. INTRODUCTION

The rapid advancement of technology in the field of engineering is significantly transforming technical systems and the organizations involved in their development. Special attention is given to complex products and systems (CPS), which often form the foundation of critical infrastructure in society. With digital transformation increasingly driven by artificial intelligence, these systems are becoming more sophisticated and intelligent [1]. The examples of such systems include autonomous vehicles, smart cities, unmanned aerial vehicles, and intelligent networks. Researchers note that digital transformation can initiate the emergence of new organizational structures and system architectures [2]. In this context, CPS, evolving into complex intelligent systems (CIS), may require changes in organizational approaches to address new development challenges.

Complex products and systems are traditionally characterized by a hierarchical structure consisting of numerous subsystems with intricate interconnections. The development of such systems requires a broad spectrum of skills and deep knowledge in systems engineering, as well as coordination among multiple stakeholders, making the design process more complex [3]. In the modern context, CPS management is largely project-based, with system integrators playing a key role in coordinating interactions between various participants, including users, suppliers, and regulators.

Systems engineering approaches for CPS are closely linked to the project cycle and serve as coordination mechanisms. To manage complexity, industries developing CPS utilize systems engineering models that represent the system from different perspectives throughout

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its lifecycle. These approaches are often based on teleology and the system lifecycle, ensuring goal-oriented development at each stage [4].

The novelty of this paper lies in describing the integration of multiple artificial intelligence methods (machine learning, natural language processing, neural networks, rule-based systems, genetic algorithms) to achieve more accurate, adaptive, and efficient decision-making at different stages of complex software project management. The study characterizes hybrid intelligent systems that combine these methods to enhance decision support under uncertainty and complexity in software projects. While the combination of artificial intelligence methods for managing complex systems has been explored in previous research, the specific integration proposed in this paper is a novel approach within the context of complex software projects. Most prior studies have typically focused on individual methods or limited combinations. For instance, machine learning or neural networks have been used solely for risk prediction without incorporating natural language processing or genetic algorithms for resource optimization. Additionally, hybrid approaches (such as agile-stage-gate) have been applied in other fields but not as comprehensively integrated into solving challenges in complex software projects. Thus, this study contributes to a novel combination of artificial intelligence technologies that have not previously been applied in such an integrated manner for complex project management.

The advancement of artificial intelligence and data processing methods opens new perspectives for CPS design. Utilizing advanced computational methods and analytics, such as big data analysis from the Internet of Things, sensors, and other sources, significantly enhances project management capabilities. As a result, CPS evolve into complex intelligent systems, which in turn creates new opportunities for society [5]. However, several challenges must be addressed, including improving the learning capabilities and adaptive mechanisms of CIS.

Thus, the modern paradigm of CPS development requires transformation. CPS must integrate project and engineering aspects into a unified development strategy that ensures a comprehensive understanding of their evolution.

2. REVIEW OF CLASSICAL METHODS

Due to the increasing role of artificial intelligence and data analysis -based methods, it is essential to understand how the foundational logic that drives the development of complex products and systems is transforming. The aim of this study is to examine the interaction between different approaches to developing complex intelligent systems (CIS) and to explore how the combination of model-based, data-driven, and hybrid approaches (such as agile-stage-gate) along with artificial intelligence methods influences the further development of complex product systems (CPS).

Due to the complexity of CPS, their development is an extremely challenging and multi-component process. K. Hansen and H. Rusch [4] identify four key factors of uncertainty: the difficulty in defining technical requirements in the early stages of a project, constantly changing requirements during development, technical uncertainties due to insufficient data, and the complexity of coordination among project participants. A phase-based process approach, which is widely used in large-scale projects (such as mechanical or chemical engineering), forms the foundation of CPS systems engineering. A crucial role in this process is played by model-based systems engineering, which allows complex systems to be represented in various models that become more detailed as development progresses [6].

Although model-based systems engineering can capture structural and behavioral aspects of systems, aspects related to context, time, and perception are often inadequately considered in models. Therefore, it is necessary to take these dynamic factors into account for a comprehensive understanding of CIS development.

With the growing role of software functions in complex products and systems, software and embedded systems development has fundamentally changed CPS design approaches, both at the level of individual projects and in the broader process context. This shift has enabled the «parallel design and production of core system components using predictive data and complex models». Software development introduces complex feedback loops between different stages, involving both customers and suppliers, while simultaneously integrating inter-project relationships.

Taking into account the increasing complexity of CPS, where software plays a key role, the conventional methods such as the waterfall approach may be insufficient for managing development processes. In cases where formal practices do not yield effective results, organizations increasingly resort to informal and human-centered practices. To effectively manage system development dynamics and adaptation to changes, it is recommended to use flexible, phased, and iterative approaches that integrate sequential and parallel processes [7].

Agile methods, such as rapid prototyping and development, were created to respond to rapid changes, focusing on continuous delivery and adaptation to evolving requirements and user needs. Agile methods combine elements of «chaos» and «order», which has led to the introduction of the term «chaordic» to describe their properties. Nevertheless, traditional planning models remain crucial for long-term project management, especially when macro-planning must be combined with micro-planning [8].

Hybrid approaches that integrate agile and stage-based methods have been successfully applied in various industries. However, the main challenge is balancing short-term and long-term orientations, which requires proper attention to emergent behavior [6]. In the context of increasing digitalization of CPS, new challenges arise in the integration of artificial intelligence and big data. The introduction of technologies such as deep learning and AI-based systems is transforming the development process, making it even more complex and demanding in terms of coordination and systems integration [3].

For example, in the development of autonomous vehicles, the use of deep learning algorithms creates difficulties in verifying and validating vehicle functionalities. Traditional systems engineering models, such as the «V» model, often fail to account for the dynamic aspects that arise during the development of systems with intelligent components [6].

At the same time, digital innovations such as the Internet of Things (IoT), big data, and cloud computing have significantly changed CPS design and development approaches, opening new possibilities for solving complex problems through data analysis.

Regarding the development of complex product systems, their complexity arises from the interconnections between subsystems and components, which together can enable capabilities beyond those of individual elements [9]. However, with the introduction of software in CPS, alternative approaches have emerged, such as agile methodologies, which offer continuous customer feedback and short development cycles. Finally, the adoption of agile and hybrid approaches, such as combining agile and stage-gate, demonstrates elements of dialectical tension and the need for a balance between long-term and short-term orientations.

3. THE SIGNIFICANCE OF ARTIFICIAL INTELLIGENCE

The current impact of artificial intelligence (AI) on project management indicates a significant transformation of the field in recent years. AI, as a technology that mimics human cognitive processes, has found applications in project management, expanding its influence across various domains. However, its integration requires a deeper understanding

of its impact on the field. Project managers, researchers, and organizations are actively analyzing AI's opportunities and challenges, making empirical studies crucial for understanding this dynamic area. Over time, project management has evolved from a labor-intensive manual process into an energetic career. Today, AI integration marks a new era, reshaping approaches to project management – from conception to execution and delivery of results [10].

AI introduces substantial innovations in project management, affecting various processes such as efficiency improvement, decision-making, role transformations within teams, and ethical considerations. In our study, we identified three key phases of this transformation: initial efforts, overcoming existing challenges, and long-term consequences. AI integration promises a true revolution in project management, particularly through the automation of routine tasks and enhanced analytics for more effective decision-making. Over time, the role of project managers will shift away from traditional responsibilities, focusing instead on areas requiring human intuition, communication skills, and deep understanding.

AI has enormous potential in areas such as random inspections, resource allocation, and predictive analytics. These innovations not only streamline workflows but also help achieve better project outcomes, making them more aligned with their goals, thereby improving overall success rates. However, despite its advantages, concerns are growing over potential job losses. It is essential to view AI as an assistive tool rather than a replacement for human efforts. As scholars emphasize [11], humans should remain in leadership roles, using AI as a supportive mechanism. Allowing machines to fully take over creative processes could strip results of essential elements of human ingenuity. The successful integration of AI depends on understanding its capabilities, properly formulating queries, and recognizing when to accept or adjust AI-generated suggestions.

Continuous learning and adaptability are key elements of successful AI interaction in project management. Its implementation offers numerous benefits, including improved decision-making, task execution optimization, better resource allocation, enhanced risk assessment accuracy, and strengthened collaboration. These advancements are significant, yet they require careful analysis of data quality to ensure optimal results [12].

In the future, AI’s role in project management will continue to grow, influencing core processes and roles. Anticipated changes will include transformations in management processes and decision-making, as well as the adoption of new project planning approaches [13]. Based on AI’s evolution in project management, it is projected that emerging technologies will continue to reshape the industry, particularly by refining workflows and integrating innovative problem-solving methods.

Artificial intelligence holds immense potential for bridging existing gaps in project management practices by introducing transformational improvements and enhancing project outcomes. However, AI tools rely on the quality of data input by project managers, and without proper management, these tools will not function effectively. Consequently, AI and project managers operate in a symbiotic relationship, requiring the latter to continually develop their skills for efficient management of intelligent systems.

By 2030, AI is expected to perform automated site inspections using LiDAR-equipped drones connected to building information management systems, intelligent contracts, and regulatory standards [14]. This will enable the detection of defects on construction sites and the prediction of potential conflicts. Such systems will allow real-time project progress assessment, profit calculations, deadline extension requests, and automated modifications without human intervention. To adapt to AI-driven work environments, human resources must focus on developing skills that complement innovative technologies.

4. INTEGRATION OF ARTIFICIAL INTELLIGENCE INTO PROJECT MANAGEMENT

The integration of artificial intelligence (AI) into project management has long attracted the attention of researchers. AI advancements, in particular, open new opportunities for enhancing project productivity, optimizing resource allocation, and improving decision-making processes [15]. However, organizations implementing these tools must examine AI's impact on employees involved in project execution [16]. It is essential to understand how AI adoption may alter personnel functions, responsibilities, and performance to ensure effective and practical integration.

While many researchers emphasize AI's benefits in project management, there is a lack of studies regarding its impact on the workforce. AI can automate routine tasks and enhance human efficiency, but its implementation also raises concerns about job reductions, shifting skill requirements, and changes in functional responsibilities. Therefore, it is crucial to develop strategies that enable the workforce to adapt to these changes, ensuring that AI integration becomes a positive experience for professionals in project management.

As AI continues to evolve, understanding how these technologies influence collaboration, data sharing, and coordination among project team members becomes increasingly important [17]. Examining these aspects will help design programs that optimize teamwork. One ongoing concern is the potential displacement of human workers due to process automation. While AI can enhance managerial decision-making, its use may lead to a reduction in human jobs, particularly in areas where tasks can be fully automated.

At the same time, other researchers argue that AI will create new opportunities for employees. The integration of AI into project management will require new skills and competencies, such as data analysis and pattern recognition [18]. This could generate new job roles for professionals with the appropriate expertise. However, there are concerns about the loss of worker autonomy and the diminishing role of human decision-making. Some scholars caution that using AI for risk assessment could result in decisions being made solely based on algorithms rather than human judgment [19].

To effectively integrate AI into project management, organizations must have clearly defined objectives. This will help in selecting appropriate AI tools for specific tasks and project types. AI continuously learns from the data provided by humans, meaning its effectiveness depends on the quality of the input information and the expertise of its users. Project managers must enhance their skills to fully leverage AI’s potential.

It is also important to consider data privacy and transparency, as data forms the foundation of AI functionality. Addressing these concerns will strengthen trust in new technologies and facilitate their integration into management processes.

The integration of multiple AI methods to address the challenges of managing complex software projects is a promising area of research, particularly in the development of hybrid intelligent decision-support systems. The primary scientific innovation of this work lies in combining several AI methods to achieve more accurate, adaptive, and efficient solutions at various stages of project management [20]. Notable methods include: combining machine learning with natural language processing; integrating neural networks with rule-based systems; applying optimization algorithms alongside genetic algorithms; incorporating multi-criteria decision-support methods; utilizing predictive analytics systems in conjunction with decision-support systems. The project management process is structurally illustrated in Figure 1.

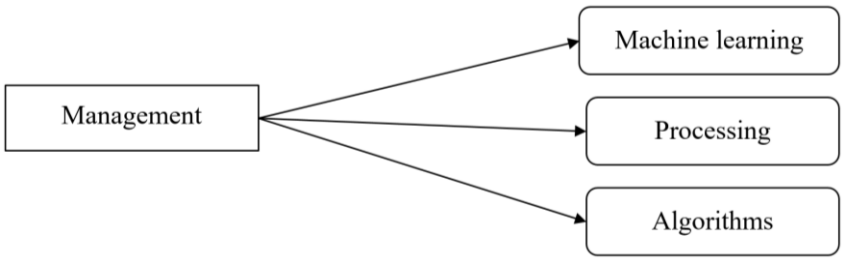

Figure 1. Structural diagram illustrating data flows between the project management process and AI methods

Source: created by the author.

Machine learning enables the creation of models that automatically predict risks, costs, or timeframes based on past project data. Natural language processing (NLP), in turn, can be integrated to analyze textual data such as reports, comments, or documentation, allowing AI to automatically identify important patterns and issues within unstructured data [21]. For example, machine learning and NLP can automate risk analysis by leveraging historical data and current documentation.

Hybrid systems can utilize deep neural networks to analyze large volumes of data and identify complex dependencies, while rule-based systems add clear and logical decision-making capabilities. This combination allows the system not only to serve as a powerful analytical tool but also to provide explanations for its decisions, which is crucial for building user trust in AI. In software projects, such hybrid systems can assist with resource management, scheduling, and task allocation.

For optimizing complex tasks such as resource allocation or planning, genetic algorithms can be combined with other optimization techniques, such as metaheuristic algorithms. These approaches enable the identification of optimal solutions for complex problems while quickly adapting strategies in time- or resource-constrained environments [22]. In software projects, these algorithms can facilitate the rapid reallocation of resources.

Decision-making in complex software projects often involves multiple criteria, such as cost, time, quality, and risk. The use of multi-criteria decision-making methods in combination with machine learning algorithms allows for the automatic weighing and evaluation of various factors, ensuring a comprehensive perspective and improving decision-making efficiency. Several methods are involved in the project management process, which can be illustrated using a Gantt chart (Fig. 2).

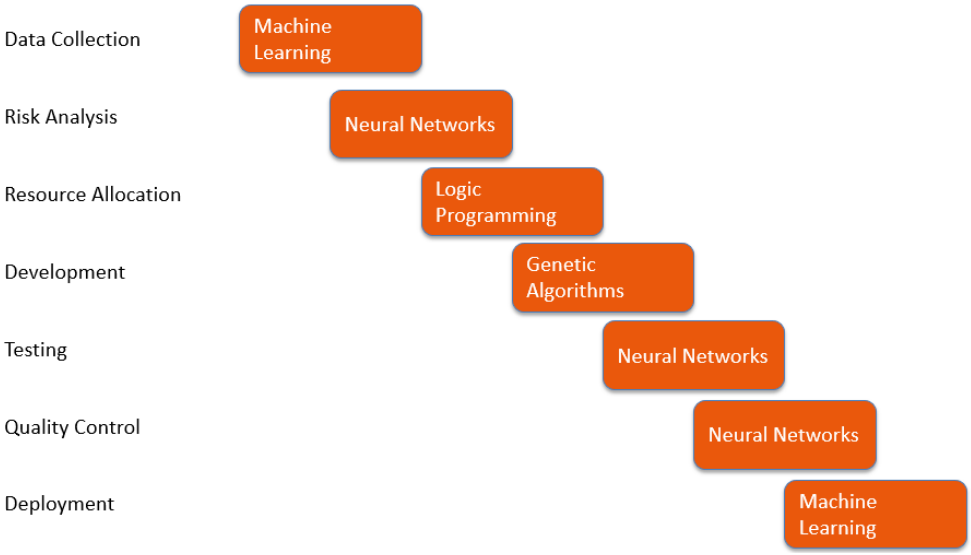

Figure 2. Gantt chart – Visualization of the integration of AI methods at different stages of complex software project management

Source: created by the author.

Predictive analytics enables the analysis of trends and provides forecasts based on historical data, while decision support systems help automatically generate recommendations for improving project management [23]. The integration of these methods is crucial to providing managers not only with forecasts but also with actionable suggestions based on the obtained data.

A specific example of integrating multiple artificial intelligence methods in software project management is the optimization of resource allocation, task scheduling, and risk management at various stages of the project lifecycle. This can be illustrated using a Venn diagram (Figure 3).

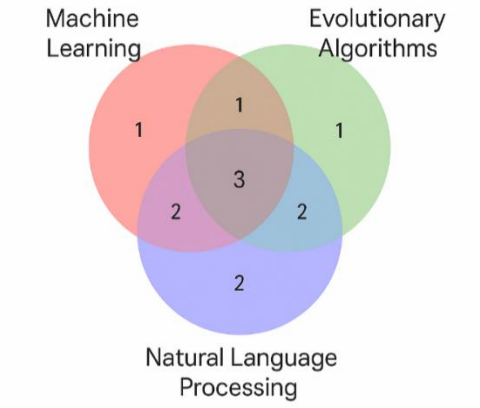

Figure 3. Venn diagram illustrating the integration of artificial intelligence methods, where 1 – the area of a single method, 2 –the intersection area of two methods, 3 – the intersection area of three methods

Source: created by the author.

The area of a single method means that this method independently solves specific tasks without requiring integration with other methods. For example, neural networks are used for image recognition or risk prediction based on historical data. Evolutionary algorithms can be applied to optimize system architecture or solve complex problems.

The intersection area between two methods indicates that these methods can be effectively used together to solve certain tasks. For instance, neural networks and machine learning can be combined to improve forecasting accuracy and create self-learning models for risk management.

The intersection of three methods defines situations where all three AI methods are integrated to solve complex problems that cannot be addressed using one or two methods alone. For example, neural networks, machine learning, and evolutionary algorithms can be integrated for the entire project lifecycle: from forecasting to resource optimization and decision-making automation.

Practical Example

Suppose a company is developing new financial sector software that requires the coordinated work of a large team of developers, testers, designers, and managers, as well as interaction with contractors and external service providers.

In practice, the integration of genetic algorithms and machine learning can be used for the efficient allocation of human resources and computing power. Machine learning, based on historical project data, can predict potential delays or overloading of individual employees, while genetic algorithms optimize these resources based on project constraints. For example, machine learning analyzes team performance data and identifies that certain team members are more effective at specific tasks, while others require more time.

Simultaneously, the genetic algorithm determines the optimal task distribution among team members, reducing downtime and resource overload.

Multi-criteria methods combined with predictive analytics enable decision-making based on multiple parameters simultaneously, such as costs, deadlines, and execution quality. For example, predictive analytics, powered by machine learning, analyzes past project data and forecasts potential risks like delays or budget overruns. A multi-criteria decision-making algorithm then evaluates the forecast and suggests schedule adjustments or resource redistribution to mitigate risks. This system helps managers adjust schedules or reallocate resources to minimize negative impacts.

Risk analysis often involves both structured data (costs, timelines) and unstructured information (reports, comments). Neural networks combined with natural language processing (NLP) can be used to identify potential risks based on both numerical indicators and textual data. For example, NLP analyzes employee reports and comments to detect negative trends or issues that may cause delays (e.g., frequent mentions of technical difficulties or team overload). The neural network then uses this data to predict the likelihood of risks and suggests recommendations for mitigation, such as allocating additional resources or revising the project schedule.

Complex software projects often require changes to plans and requirements. Rule-based systems combined with neural networks can automate change management processes. For example, neural networks analyze the current project state, data on changes, and their impact on resource and time constraints. Then, the rule-based system automatically generates change management scenarios, considering the identified impacts, and proposes multiple adaptation options (e.g., adjusting deadlines, increasing resources, revising priorities).

Integrating all these methods allows for a system that automatically generates feedback and recommendations for project managers, helping them make decisions based on real-time data analysis. This minimizes human error and enables quick responses to project changes. In practice, such AI integration solves a wide range of challenges in managing complex software projects – from planning and resource allocation to risk prediction and change management. This enhances project efficiency, reduces risks and costs, and is a key factor in the success of complex software projects in modern environments.

5. CONCLUSIONS

The development of hybrid intelligent decision-support systems for managing complex software projects is an important and relevant research direction that opens new opportunities for improving management efficiency. Technological progress and artificial intelligence (AI) advancements are radically transforming approaches to designing and managing complex products and systems. The integration of hybrid intelligent systems that combine various AI methods—such as machine learning, natural language processing, neural networks, rule-based systems, optimization, and genetic algorithms – enables more precise, adaptive, and efficient decision-making at different stages of project management.

Digital transformation and the use of advanced computational methods, such as big data analytics, make systems increasingly complex and intelligent, requiring new organizational approaches. Traditional methods, such as the waterfall model and stage-gate approaches, no longer fully address the challenges of modern complex systems management. Hybrid approaches that combine agile and stage-based methodologies allow better adaptation to development dynamics and changes.

AI introduces significant innovations in project management, including automation of routine tasks, enhanced analytics, and improved decision-making efficiency. However, AI

integration requires careful consideration to balance automation with human input while ensuring high data quality and ethical technology use.

Continuous learning and adaptation to new conditions are key to successfully integrating AI into project management. Organizations should focus on developing skills that complement innovative technologies and ensure proper query formulation and data management for maximum results. In the future, AI's role in project management will continue to grow, requiring new approaches to project planning and execution, as well as a deeper understanding of its impact on the workforce.

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РОЗРОБЛЕННЯ ГІБРИДНИХ ІНТЕЛЕКТУАЛЬНИХ СИСТЕМ ДЛЯ ПІДТРИМАННЯ ПРИЙНЯТТЯ РІШЕНЬ У СКЛАДНИХ ПРОГРАМНИХ ПРОЄКТАХ

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***Резюме**. У сучасних умовах цифрової трансформації та зростання складності управління програмними проєктами особливої актуальності набуває створення інтелектуальних систем підтримання прийняття рішень. Запропоновано підхід до побудови гібридної інтелектуальної системи, яка інтегрує методи штучного інтелекту, аналізу великих даних, агентного моделювання та гнучкі методології управління проєктами. Основна увага приділена адаптації системи до динамічних змін середовища та високого рівня невизначеності, що притаманні сучасним IT-проєктам. Запропоновано нові алгоритми, здатні підтримувати ефективне прийняття рішень в умовах обмеженого часу, змін вимог замовника та технологічної складності. Під час моделювання встановлено, що розроблена система дозволяє знизити ризики реалізації програмних проєктів на 22% та підвищити точність планування й вибору оптимальних управлінських рішень на 18%. Особливу увагу приділено здатності системи забезпечувати гнучке перепланування ресурсів і завдань у режимі реального часу. Результати дослідження підтверджують доцільність застосування гібридного підходу, який поєднує машинне навчання, опрацювання природної мови, нейронні мережі, продукційні правила та генетичні алгоритми. Це забезпечує не лише аналітичне підтримання, але й пояснюваність рішень, що підвищує довіру користувачів. Практичне впровадження таких систем може суттєво підвищити якість, керованість та ефективність складних програмних проєктів в умовах швидкоплинного IT-ринку. Система забезпечує масштабованість для адаптації до різних типів проєктів. Застосування таких підходів сприяє розвитку інноваційних технологій у сфері управління. Особливу цінність система має для команд, що працюють у розподіленому середовищі. У подальшому планується розширення функціональності з урахуванням нових викликів галузі.*

***Ключові слова:** гібридні інтелектуальні системи, підтримка прийняття рішень, складні програмні проєкти, штучний інтелект, інтеграція методів.*

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