The Use of Adaptive Artificial Intelligence (AI) Learning Models in Decision Support Systems for Smart Regions

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Abstract

The purpose of this study is to analyse the effectiveness of implementing adaptive AI learning models in decision support systems to optimise the functioning of smart regions. The study provides a detailed examination of the application of machine learning algorithms, deep learning, and reinforcement learning across various sectors, such as urban management, energy resources, and security. The results revealed that the implementation of these models enhances the efficiency of urban system management, reduces costs, and increases the flexibility of decision-making processes. In particular, adaptive models in energy resource management optimise decision-making processes, leading to more rational resource use and substantial cost reductions. In the security field, adaptive AI models show improvements in predicting and preventing incidents, ensuring more reliable and stable system performance. Moreover, the results include the implementation of adaptive models based on programming languages such as TypeScript and JavaScript. The study demonstrated that the use of TypeScript reduces errors and improves system scalability due to strict typing, as shown in the implementation of a reinforcement learning model. Meanwhile, the use of JavaScript enabled the effective adaptation of models to new data through dynamic updates of regression coefficients, leading to improved prediction accuracy.

Keywords: automation of management; resource optimisation; efficiency enhancement; digital technologies; TypeScript; recommendation system.

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Introduction

Adaptive learning models of artificial intelligence (AI) form the foundation of modern automation and management systems, utilising data to optimise processes and decision-making. These technologies play a crucial role in various sectors, including urban management, energy management, and security. Their application allows for more efficient resource management, reduced costs, and improved quality of life in "smart" regions (areas where digital technologies are actively implemented to enhance management efficiency, optimise resources, and improve the population's quality of life). With the rapid development of technology and the growing volume of data being processed, conventional methods of resource management and decision-making are becoming increasingly inefficient (Aizenberh, 2024; Nurbatsin et al., 2024). The issue addressed in this study lies in the insufficient integration of adaptive AI models into Decision Support Systems (DSS) within the context of smart regions. The lack of comprehensive solutions for process optimisation across various sectors presents challenges for management structures (Hoxha et al., 2025; Minakova & Grigori, 2023).

Intelligent decision technologies, such as data warehouses, optimization systems, and intelligent agents, serve as important components in enhancing the responsiveness of Decision Support Systems (DSS) within smart regions. These tools enable more efficient planning, resource allocation, and strategic decision-making across sectors such as transportation, energy, and public services. In the context of smart regions, where data flows are vast and decision environments are increasingly complex, such technologies support adaptive AI learning models by providing structured data environments, real-time analytical capabilities, and automated responses. As Ștefănescu (2011) highlights, intelligent decision support systems leverage advanced technologies including data mining, simulation, multi-agent frameworks, and fuzzy logic, each of which plays an important role in supporting distributed, web-based, and remotely coordinated decision-making. Their integration into DSS not only enhances predictive accuracy and process optimization but also boosts system resilience and agility in urban ecosystems.

It is essential to understand how adaptive models can enhance the efficiency of management systems, the advantages that advanced programming languages offer in the implementation of such models, and how their adoption can resolve existing problems related to optimisation and forecasting accuracy.

For a deeper understanding of the research context, it is important to consider similar studies. For example, Savytskyi & Orlova (2020) explored the methods and features of building "smart home" systems using artificial intelligence. They analysed user interactions with AI systems and smart home modules, identifying the main areas of application for these technologies. Osmak et. al. (2023) examined the primary advantages, development prospects, and risks of using AI tools in network management, identifying the key tasks and functions of AI algorithms in these systems and offering recommendations on approaches to the development of applied models and their regulatory framework. Symonov (2024) highlighted the importance of AI application in management, emphasising its role in the automation of processes, the improvement of decision-making based on the analysis of large volumes of data, and providing examples of successful AI implementation in project management.

In turn, Singhal et al. (2024) examined the importance of employing explainable AI models in decision-making within smart healthcare systems. They proposed a novel framework integrating such models with deep learning (DL) and advanced medical imaging techniques, enhancing both the accuracy and trust in AI-driven solutions for medical applications. Selvarani et al. (2023) highlighted the pivotal role AI and machine learning (ML) play in transforming conventional manufacturing into smart manufacturing. Their study emphasised the application of AI and ML in data-driven decision-making, predictive maintenance, and integration with the Internet of Things.

In addition, Chakraborty et al. (2022) demonstrated the role of enterprise management systems and big data analytics in the development of AI, information science, and statistics, focusing on the use of distributed systems for processing large data volumes and supporting decision-making processes. The research of García-Sigüenza et al. (2023) presented an AI model for creating a learning system based on the principles of the Customized Adaptive Learning Model (CALM). This system employs DL to predict and select the most appropriate learning activities, enabling educators to manage the learning process more effectively.

Similarly, Ullah et al. (2024) showcased the use of AI, IoT, and data science in future communication systems aimed at creating dynamic, self-learning network environments with high reliability and minimal latency. Kommineni & Baseer (2024) underscored the importance of AI in transforming raw data into valuable information for decision support, stressing the need for high-performance computing infrastructures to ensure rapid response in smart cities. Moreover, the findings of Rane et al. (2024) demonstrated that AI and ML technologies have significantly improved renewable energy forecasting, optimising energy production and distribution, while supporting real-time decision-making and adaptive control in smart energy systems. After analysing the aforementioned studies, it is clear that not all of them address the integration of adaptive AI models into the key aspects of smart regions. This study, however, seeks to fill these gaps by examining the effectiveness of adaptive AI models across different sectors and their implementation through programming languages.

Overall, this study focuses on analysing the effectiveness of implementing adaptive AI learning models in Decision Support Systems (DSS) to optimise the functioning of smart regions. The objectives include reviewing adaptive AI learning models in DSS within smart regions and demonstrating their implementation using programming languages such as TypeScript (TS) and JavaScript (JS).

1. Materials and Methods

This study evaluated how adaptive artificial intelligence models, specifically machine learning, deep learning, and reinforcement learning models, can enhance management efficiency in various domains, including urban and energy management, and safety. A detailed analysis of these models was conducted, alongside a schematic representation of their functioning, incorporating supervised and unsupervised learning, algorithms for ML, training in DL, and its architecture, which included Convolutional Neural Networks (CNN), Recurrent Neural Networks (RNN), and Generative Adversarial Networks (GAN). Moreover, methods and components of Reinforcement Learning (RL) were explored. This allowed for the identification of the key characteristics of each method and an understanding of how they can be adapted to the specific requirements of smart regions.

Subsequently, the application of adaptive AI models in optimising urban management was compared. At this stage, the advantages and disadvantages of using adaptive models in urban resource management, transportation, and communications were analysed. Examples of the implementation of ML, DL, and RL models to improve urban management efficiency were examined, particularly in reducing costs and increasing the speed of decision-making. The application of adaptive AI models in energy resource management was also compared. This phase of the study focused on analysing models used to optimise energy consumption and resource management. Adaptive models that facilitate energy loss reduction and improve the efficiency of renewable energy use were examined. Within this phase, the risks and challenges associated with using AI in the energy sector were also analysed. Finally, a comparison of adaptive AI models in enhancing safety was undertaken. The study investigated how AI can be used to predict and prevent incidents that pose safety risks. The analysis explored how adaptive models can improve the efficiency of security systems, particularly in predicting suspicious activities.

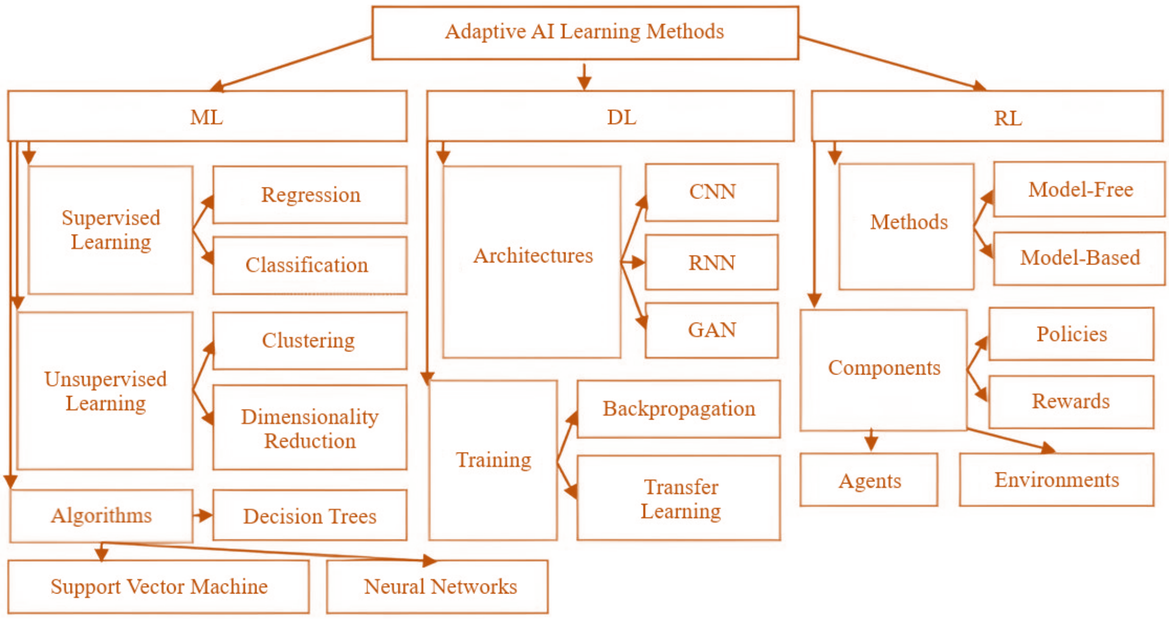
An important aspect of the study was identifying key criteria for analysing the efficiency of adaptive AI models. The specific metrics used to evaluate the effectiveness of these models were defined. To provide a more detailed demonstration of the application of adaptive AI models, simple programmes were developed using TypeScript and JavaScript. In TypeScript, strict typing was employed to clearly define data structures and functions, ensuring code reliability. The code example illustrated how this typing helps define states, actions, and rewards in an RL model, ensuring the correct implementation of the model. This was done using the TS Playground online platform. On the other hand, in JavaScript, an example code was provided where the model adapts to new data by updating regression coefficients, demonstrating the model's dynamic adjustment to changing input data and improved prediction accuracy. This was performed using the JavaScript Online Compiler.

2. Research Results

2.1. Overview of adaptive AI learning models in decision support systems for smart regions

Adaptive AI learning models form the foundation of modern DSS, particularly in smart regions. These models enable systems to analyse large volumes of data, learn from it, and adapt to new conditions, enhancing the efficiency of management processes. Adaptive AI learning models employ various algorithms for data analysis, among which machine learning, deep learning, and reinforcement learning are prominent (Figure 1). ML relies on algorithms that allow systems to learn from data autonomously and gradually improve their performance without the need for explicit programming (Nekrasov et al., 2022; Shults & Annenkov, 2023). In this context, systems learn from historical data, make predictions or classifications, and, over time, their accuracy and efficiency improve through continuous data updates and adaptation to new conditions. DL, a subset of machine learning, is characterised by the use of neural networks with multiple layers, enabling the processing and analysis of large amounts of unstructured data, such as images, text, or audio (Dahan et al., 2015; Havran & Orynchak, 2024; Markhaba et al., 2024). It is capable of detecting complex patterns and dependencies in data, making it an extremely powerful tool for tasks such as image recognition, natural language processing, and forecasting. RL, on the other hand, is a method where agents learn to make decisions through interaction with their environment. Agents receive rewards or penalties for their actions, allowing them to optimise their behaviour to maximise overall rewards (Domashenko, 2024; Petrovskyi et al., 2025). This method is used to develop strategies in complex environments, such as games, robotics, and autonomous systems.

Figure 1. Methods of adaptive AI training models



Source: Created by the authors.

Overall, adaptive AI models hold tremendous potential for enhancing the functionality of smart regions. They are used to optimise various aspects of urban management, energy resources, and security. They are used to optimise various aspects of urban management, energy resources, and security. In smart regions, traffic management represents one of the most illustrative scenarios where adaptive AI models significantly enhance system efficiency. These models are employed to address complex tasks such as real-time traffic flow regulation, congestion prediction, route optimisation, and emergency response coordination (Zarichuk, 2023; Zaivyi & Melnychok, 2025). The AI system receives input data from various sources including road sensors, GPS trackers, traffic cameras, and connected vehicles. It processes this data using machine learning and deep learning algorithms to identify traffic patterns, detect anomalies, and forecast congestion points (Bayegizova et al., 2024;

Rexhepi et al., 2023). Based on the processed information, the system makes autonomous decisions, for example by dynamically adjusting traffic signal timings, suggesting alternative routes to drivers, or prioritising emergency vehicle pathways. The implementation of such AI-driven models leads to improved traffic fluidity, reduced travel times, lower fuel consumption, and a decrease in CO_2 emissions, thereby enhancing both urban mobility and environmental sustainability (Wolniak & Stecuła, 2024).

However, despite the significant benefits, challenges remain in ensuring data quality, integrating legacy infrastructure, maintaining cybersecurity, and addressing privacy concerns. The success of such systems depends heavily on the consistency and accuracy of input data, the adaptability of algorithms to unpredictable conditions, and the readiness of urban infrastructure to support real-time digital interaction (Trofymchuk et al., 2019; Xhafka et al., 2015). Nonetheless, when effectively implemented, adaptive AI in traffic management stands as a powerful tool in transforming urban transport systems into more responsive, efficient, and resilient components of smart regions.

For example, adaptive AI models can improve the efficiency of urban management in areas such as traffic control, lighting, and utility services (Table 1). AI systems can analyse data from road sensors, surveillance cameras, and GPS trackers to adjust traffic light signals in real time. This helps reduce congestion, improve traffic flow, and decrease travel time for drivers.

Table 1. Comparison of the application of adaptive AI models in optimising urban management

Field of application	Advantages	Disadvantages	Examples of use
Traffic management	▪ Reduces congestion	▪ High implementation cost	▪ Automatic traffic light adjustment to optimise traffic flow
	▪ Improves traffic flow ▪ Decreases travel time for drivers	▪ Dependency on the quality of input data	▪ Adaptive traffic management based on data analysis from cameras and sensors
Lighting	▪ Reduce energy costs	▪ Potential for technical failures	▪ Automatic brightness adjustment based on the presence of people and lighting conditions
	▪ Enhances street safety ▪ Improves environmental efficiency	▪ Dependency on climate and weather conditions	▪ Lighting that adjusts intensity based on the presence of pedestrians and cyclists
Utilities	▪ Optimises water supply and drainage	▪ High complexity of implementation	▪ Prediction of leaks and malfunctions in water supply and drainage systems
	▪ Reduces maintenance costs ▪ Increases service efficiency	▪ Requires significant resources to process large amounts of data	▪ Optimisation of waste collection and disposal using AI-based predictive models

Source: created by the authors.

Moreover, AI-based lighting systems can adjust streetlight brightness depending on natural light levels and the presence of pedestrians or vehicles, reducing energy costs and increasing street safety. AI can also optimise water supply and drainage systems, predict leaks or malfunctions, and manage waste more efficiently, reducing costs and improving service effectiveness (Makhazhanova et al., 2024). Quantitatively, adaptive AI models have been shown to reduce decision-making time by approximately 25%, achieve cost savings between 15 and 18%, and improve prediction accuracy by up to 30%, demonstrating significant enhancements in operational efficiency and resource optimisation (Shamim et al., 2025). These metrics underscore the transformative impact of AI on smart region management across multiple domains.

Adaptive AI learning models also play a key role in the energy sector, particularly in forecasting energy consumption, optimising energy distribution, and integrating renewable energy sources (Table 2). For instance, AI can analyse historical data and weather conditions to predict future energy consumption, allowing energy companies to plan and manage their resources better (Romankiewicz et al., 2023; Turchyn, 2025). AI systems can adapt to changes in energy demand, optimising distribution across different areas, which helps reduce production and transportation costs. Moreover, AI can manage renewable energy systems, such as solar panels and wind turbines, to maximise their performance and ensure a stable energy supply (Orazbayev et al., 2024; Torepashovna et al., 2022).

Table 2: Comparison of the application of adaptive AI models in energy resource management

Field of application	Advantages	Disadvantages	Examples of use
Energy consumption forecasting	▪ Accurate energy consumption forecasting, allowing for better resource planning ▪ Reduces excess expenditure and losses through precise planning	▪ High dependency on the quality of historical data and model accuracy	▪ Use of weather data to optimise energy supply
Energy distribution optimisation	▪ Lowers production and transportation costs ▪ Improves resource utilisation efficiency	▪ Risk of incorrect decisions during unexpected demand changes	▪ Optimisation of energy flows between districts in real-time
Integration of renewable energy sources	▪ Maximises renewable energy source productivity ▪ Ensures stable energy supply regardless of external factors	▪ Complexity of integration with traditional energy supply systems	▪ Stabilisation of energy supply through forecasting and management of renewable energy performance

Source: created by the authors.

Furthermore, AI systems are used to enhance security in smart regions. This includes analysing video surveillance footage and managing access control (Table 3). AI can analyse video streams from cameras to detect suspicious behavioural patterns, such as unusual activity or behaviour that may indicate potential threats (Semenenko et al., 2024). This allows law enforcement agencies to respond more quickly to potential incidents. Furthermore, AI systems can monitor access to sensitive areas, automatically identifying and preventing unauthorised entry attempts.

Table 3: Comparison of the use of adaptive AI models in improving security

Field of application	Advantages	Disadvantages	Examples of use
Video surveillance analysis	▪ Rapid detection of potential threats through the analysis of behavioural patterns ▪ Increases the speed of law enforcement responses to incidents	▪ Possible false positives and the need for careful algorithm calibration	▪ Automatic video stream analysis to identify suspicious activities at transport stations
Access management	▪ Efficient control of access to sensitive areas using biometric data and other methods	▪ Potential issues with privacy and protection of personal data	▪ AI-based automatic access control to prevent unauthorised entries

Source: created by the authors.

Adaptive learning AI models contribute to social integration and enhance public participation. They enable the personalisation of services for citizens, tailoring them to individual needs and improving overall satisfaction levels. Moreover, the analysis of data from social media and other sources assists local authorities in understanding public sentiment and responding promptly to social challenges (Bilovodska et al., 2024; Xhafka et al., 2024). With these capabilities, adaptive AI models make smart regions more efficient, environmentally sustainable, and secure, thereby supporting their sustainable development (Shebanina et al., 2025).

To assess the effectiveness of implementing adaptive AI models in decision support systems, several criteria should be considered, including performance, cost-effectiveness, and flexibility. Performance encompasses decision-making time, which involves reducing the time required for managerial decisions, and the quality of decisions, meaning improvements in the accuracy and relevance of decisions through the analysis of large datasets (Cherniavska & Cherniavskyi, 2024; Cherniavska et al., 2024). In terms of cost-effectiveness, this includes cost reduction, such as lowering maintenance and resource management expenses through the automation and optimisation of processes, as well as increased efficiency, characterised by a reduction in energy and resource expenditure through more effective utilisation. Flexibility, on the other hand, includes the ability to adapt to changing conditions, meaning the capacity of systems to adjust to environmental changes or new challenges, and responsiveness to new challenges, defined as the ability to react swiftly to emerging issues and adapt to new requirements or situations (Annenkov et al., 2023; Kharchenko et al., 2017; Shults et al., 2023). Thus, adaptive learning AI models are an integral part of modern decision support systems in smart regions. They ensure more efficient resource management, improve the quality of life for citizens, and contribute to the sustainable development of regions. Due to their ability to adapt to changing conditions and respond quickly to new challenges, these models enable the implementation of innovative solutions in various sectors, such as urban management, energy, and security (Oliinyk et al., 2025). The overall impact of adaptive AI models on the functioning of smart regions highlights their key role in ensuring a high level of efficiency, cost-effectiveness, and flexibility in management processes. Systems based on these models help create more intelligent, sustainable, and secure environments that meet contemporary demands and challenges.

2.2. Examples of implementation using strictly typed programming languages: TypeScript and JavaScript

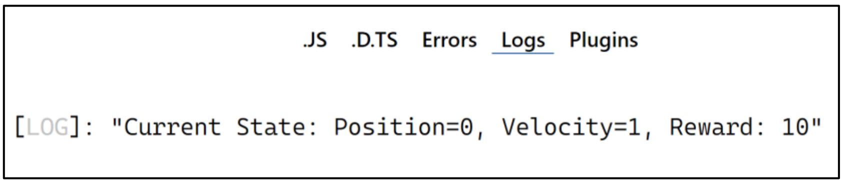
Adaptive learning AI models are the foundation of many modern applications, and an important aspect of their implementation is the choice of programming language. In this context, strictly typed programming languages are of particular significance. Notably, TypeScript (TS) and JavaScript (JS) are widely used in the development of AI systems due to their flexibility, ease of integration, and ability to provide high performance and software stability (Serediuk, 2024). TS, a strictly typed superset of JS, has gained increasing popularity in this domain due to its ability to offer the flexibility of JS alongside the advantages of static typing. The use of TS in AI applications, particularly those related to adaptive learning models, offers several advantages. One of the most significant benefits is the prevention of runtime errors through static typing, which is especially crucial in complex AI systems where data flow and transformations are intricate (Antoniuk & Kolyada, 2023). Type annotations and interfaces in TS enable developers to define clear contracts for data structures and functions, reducing the risk of errors arising from improper data handling. This is particularly important in AI applications, where data integrity and accuracy are essential (Yemchenko, 2024).

Furthermore, TS improves code readability and maintainability, facilitating teamwork on large AI projects. As AI systems evolve and require frequent updates or scaling, the strict typing in TS can help prevent regressions and ensure the smooth integration of new features with the existing codebase (Ye et al., 2024). This is particularly critical in adaptive AI models, where the system must continually learn and adapt to new data, necessitating frequent code changes-A practical example of TypeScript (TS) usage is demonstrated through the development of a basic decision-making model using a reinforcement learning (RL) algorithm.

In this context, the supplementary file (part A) provided include a code example that illustrates how TS's strong typing features can be used to clearly define states, actions, and rewards within the RL model.-This code presents a simple example of implementing a RL model using TypeScript. The RL model employs object-oriented programming to simulate a basic learning process, where an agent performs actions within an environment and receives rewards based on its actions. The program begins by defining types and interfaces. The State describes the system's condition, including position and velocity. Action defines the possible actions an agent can take: "accelerate", "decelerate", or "maintain". The RLModel interface outlines the structure of the reinforcement learning model, which includes methods for performing actions, updating the state, and calculating rewards.

The SimpleRLModel class implements this interface. Upon creating an object of the class, the initial state and reward are initialised. The performAction method changes the system's state based on the action taken. For instance, with the "accelerate" action, the velocity increases by one unit, while "decelerate" decreases it. After performing the action, the state is updated, and a new reward is calculated. The calculateReward method provides a straightforward reward function: if the velocity is greater than zero, the reward is 10; otherwise, it is -10. This implies that the agent receives a positive reward for accelerating and a negative one for decelerating if the velocity is non-positive. When the code is executed, an instance of SimpleRLModel is created with an initial state where both position and velocity are set to 0. The "accelerate" action is then performed, increasing the velocity by one unit. Following this action, the system state is updated, and a new reward is computed. The outcome indicates that the agent's velocity has increased to 1 (due to the "accelerate" action), and the reward is 10, as the velocity is positive (Figure 2).

Figure 2. Code result in TS



Source: created by the authors.

In general, TypeScript (TS) can enhance the development of AI applications by making the code more comprehensible and less prone to errors, which is critical for creating reliable and efficient AI solutions. Conversely, JS, as a dynamically typed programming language, possesses unique advantages and limitations when implementing AI models. Although it does not support strict typing like TS, it remains a popular choice due to its simplicity, versatility, and extensive ecosystem of libraries and frameworks (Aviv et al., 2024; Dahan & Keller, 2018). The language is actively used for developing web applications, including user interfaces for AI systems.

In the context of AI, JS is often employed to create user interfaces that interact with AI models built in other languages (Tokarieva et al., 2024). For instance, in projects requiring real-time interaction between AI models and users, JS facilitates rapid and flexible integration.

An example of a simple predictive model using a linear regression algorithm to forecast energy consumption based on temperature is worth mentioning. The supplementary file (part B) includes a code sample demonstrating how the model adapts to new data by updating its regression coefficients in response to the results. In this code, the EnergyPredictionModel implements a simple linear regression algorithm to predict energy consumption based on temperature. The model uses two key parameters: slope and intercept. These parameters define the shape of the linear function used to estimate energy consumption. The predict method uses these parameters to calculate the predicted energy consumption based on input temperature. The formula this.slope * temperature + this.intercept implements linear regression, where temperature is the independent variable, and the result is the estimated energy consumption. This method allows predictions to be made based on the current values of the model's parameters. The updateModel method is responsible for updating the model's parameters based on new data. It uses a simple form of gradient descent to improve prediction accuracy. Gradient descent is an optimisation method that helps find the optimal parameter values for the model (Tkachenko et al., 2025). In this case, the slope and intercept parameters are updated based on the error between the actual and predicted energy consumption. The regression line's slope and intercept are adjusted, taking the learning rate into account, allowing the model to better adapt to new data.

In the usage example, the model is created and trained based on a dataset consisting of temperatures and actual energy consumption values. Specifically, for each temperature and corresponding energy consumption value, the model is updated. This allows the model to adapt to new data and improve the accuracy of its predictions. After training, the model is used to predict energy consumption for a new temperature. When the code is executed, the result is a prediction of energy consumption for the given temperature. It shows that for a temperature of 22°C, the model predicts energy consumption at -21,283 units (Figure 3).

Figure 3. Result of the code in JS

```
Console ×
Predicted Energy Usage for 22°C: -21283.423761000002
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Source: created by the authors.

This example highlights how JavaScript can be effectively employed to implement simple adaptive models, such as the energy consumption prediction model. However, the lack of static typing may lead to potential execution errors, which should be considered when developing more complex systems. Thus, the use of strongly typed programming languages, such as TypeScript, in the context of AI application development offers several advantages, including enhanced code reliability, improved performance, and simplification of the development process. JavaScript, due to its flexibility and extensive support, also remains a crucial tool for implementing interactive AI applications. Both languages can be successfully employed to develop adaptive AI models that optimise the functioning of smart regions and ensure high efficiency in decision support systems.

3. Discussion

This paper has thoroughly examined adaptive AI models in decision support systems aimed at improving the operation of smart regions. The results demonstrate increased efficiency in urban management, optimisation of energy resource management, and security through the use of machine learning, deep learning, and reinforcement learning algorithms. These findings confirm the high efficacy of adaptive models in various areas of application and highlight the advantages of using strongly typed programming languages to enhance the reliability and scalability of systems. However, to better understand this subject, it is important to analyse how this research relates to other similar studies. For example, Demertzis et al. (2022) demonstrated that innovative cybersecurity systems improve the security of energy networks but increase the risk of attacks. This study complements their approach by focusing on reducing energy losses and improving the efficiency of renewable energy use. The results of this study also indicate that the implementation of adaptive AI models significantly optimises the use of energy resources in smart regions, particularly by reducing energy losses and enhancing the efficiency of renewable energy utilisation. This aligns with the findings of Mustafa et al. (2024), who proposed the use of AI to optimise irrigation systems, which reduces water loss and increases the efficiency of water resource management.

While researchers such as Wang et al. (2024) emphasised the potential of quantum computing combined with AI to advance smart cities, with a focus on quantum approaches to solving issues related to urban planning, transportation, and communication, this study focused on the use of adaptive AI models for resource management optimisation in smart regions. The results of this study also showed that adaptive AI models improve decision-making efficiency in management by adapting their algorithms to changing conditions, which resonates with the conclusions of Pardosi et al. (2024), who demonstrated that AI successfully personalises decision-making in the education sector. This affirms the versatility of AI in enhancing the efficiency of various systems, even when the areas of application differ. Moreover, this study demonstrated that adaptive AI models effectively optimise the functionality of smart regions, contributing to cost reduction and increased efficiency. This contrasts with the findings of Ali (2024), who noted that the implementation of AI within the framework of “Smart Bangladesh” faces challenges such as insufficient efficiency and ethical concerns. This suggests that while AI holds the potential to enhance efficiency, its implementation encounters social and ethical challenges. This study showed that adaptive

AI models in energy resource management significantly reduce costs and improve the efficiency of renewable energy use. This aligns with the findings of Aggarwal et al. (2024), who indicated that AI and machine learning can enhance financial management through more precise analysis and process optimisation, though they also face ethical and regulatory challenges.

The study also demonstrated that adaptive AI models substantially improve decision-making processes in urban infrastructure management through automated data analysis and dynamic adjustment of management strategies. This complements the findings of Reddy and Tiwari (2024), who noted that in Industry 4.0, adaptive AI systems personalise learning by dynamically adjusting curricula according to student needs, contributing to more efficient management of educational processes. In addition, the results of this study showed that adaptive AI models can effectively improve decision-making in smart regions by automatically adjusting strategies based on data. This corresponds with the findings of Alloulbi et al. (2022), who found that AI positively impacts decision-making processes in smart cities by reducing technological anxiety and improving the effectiveness of decisions. In turn, this research demonstrated that the implementation of adaptive AI models significantly enhances the accuracy of predictions and the adaptation of management decisions in smart regions. This contrasts with the findings of Yildiz & Uğur (2022), which focused on the use of AI in smart manufacturing systems to improve production efficiency and quality. Unlike the work of Vergara et al. (2024), whose results focus on the integration of AI in learning management systems to improve personalisation in education, the current study emphasised the use of adaptive AI models in broader contexts of resource management and security in smart regions. It also showed that adaptive AI models in decision support systems significantly enhance decision-making efficiency due to their ability to adapt to new conditions.

As for the paper by Syafral et al. (2024), which focused on the use of AI for adaptive learning in educational institutions, the present study expanded the application of adaptive AI models, demonstrating their effectiveness not only in education but also in the management of smart regions. On the other hand, the findings of Qin and Zhong (2024) showcased the implementation of adaptive AI systems in language learning. This paper on adaptive learning models has demonstrated how these adaptability principles can be applied to a wide range of management functions in smart regions, highlighting that such models not only improve learning but also optimise management processes in real time. In comparison with the work of Philip et al. (2023), which focused on the use of AI and IoT for remote health monitoring in the context of smart cities, the current study emphasised the importance of adaptive AI systems for optimising various management processes in such cities, providing dynamic and adaptive solutions for complex systems. Similarly, the study by Padmavathi (2021) focused primarily on the use of AI and ML to improve healthcare services and infrastructure in smart cities. In contrast, this study expanded this understanding by focusing on the integration of adaptive AI models to improve personalised services across various sectors, offering a broader approach to optimising the functioning of smart regions.

The findings of Tsihrintzis et al. (2024) highlighted various aspects of decision support through AI, such as personalised recommendations and dynamic decision-making support. The study complements those results by specifically emphasising the integration of adaptive AI models to improve not only recommendations but also the overall efficiency of decision-making processes in smart regions. This study further demonstrated that the implementation of adaptive AI models significantly enhances the efficiency of DSS in smart regions, ensuring dynamic adjustments to decisions based on new data and adaptation to changing conditions. Regarding the study by Pathak et al. (2023), its approach also utilises AI for optimisation but is focused on specific agricultural tasks, including the use of AI drones. Thus, the present study on adaptive models differs in its broader application of these models for comprehensive management in smart regions.

The common aspects between this study and the work of Malvasi et al. (2024) lie in their use of adaptive AI models to improve decision-making in complex systems. However, the present study demonstrated the effectiveness of AI in smart regions for optimising management processes, whereas the other study applied AI specifically to support medical decision-making. Furthermore, in contrast to the findings of Indriastuti et al. (2023), which focused on resource management and adaptation to changing dynamics in educational institutions using AI, this study concentrated on a comprehensive analysis of AI's impact on various management aspects in smart regions. This includes economic, environmental, and social dimensions, providing a broader range of solutions to improve management across multiple sectors (Shevchuk & Radelytskyy, 2024).

While the research of Al-Fayyadh et al. (2021) focused on the use of spiking neural networks for adaptive learning, the present study established that adaptive AI models are more effective in addressing management tasks in smart regions due to their ability to quickly respond to new data and conditions. Moreover, whereas this study emphasised resource management optimisation in smart regions, the work of Yasin Ghadi et al. (2024) focused on the application of AI and ML to improve cybersecurity specifically in smart networks. Therefore, the conducted study thoroughly analysed the implementation of adaptive AI models in DSS for smart regions. Unlike other studies, which predominantly focused on specific areas such as cybersecurity, educational systems, or the application of AI in narrow fields, this study demonstrated the extensive potential of adaptive AI models for the holistic improvement of management processes in smart regions.

Conclusion

This study established that the implementation of adaptive artificial intelligence models in decision support systems significantly enhances the management efficiency of smart regions. It was confirmed that these models are capable not only of improving the accuracy and speed of decision-making but also of optimising resource utilisation. This is achieved through the ability of adaptive models to engage in automatic learning and adapt to changing conditions, making them particularly effective in dynamic environments.

It was established that the use of adaptive models in energy resource management significantly reduces energy losses and enhances the efficiency of renewable energy utilisation. In the domain of security, these models demonstrate high effectiveness in predicting and preventing incidents, thereby increasing the reliability of security systems. Furthermore, the implementation of adaptive models in urban management contributes to the optimisation of resource use and the improvement of management efficiency. Regarding technical implementation, the results indicate that employing TypeScript in the development of adaptive models reduces the number of coding errors and enhances system scalability. Therewith, the dynamism of JavaScript allows for effective adaptation of models to new data, improving the accuracy of predictions and facilitating rapid system adaptation to changes in the external environment.

Based on the findings of this study, it is recommended to continue the integration of adaptive AI models across various management sectors within smart regions, particularly in the management of urban infrastructure and transportation. Future research could focus on optimising interactions between different adaptive models and enhancing their compatibility with other technologies, such as IoT and quantum computing. However, there are certain limitations to this study. One of the key constraints is the complexity of ensuring the ethicality and transparency of decisions made based on adaptive AI models. This could create risks related to accountability for the decisions taken and potential social consequences. There are also technical challenges associated with integrating adaptive models into existing management systems. To address these limitations, it is essential to develop additional mechanisms for oversight and regulation of AI use in critical systems.

Credit Authorship Contribution Statement:

All authors contributed equally to the development and completion of this research. Pavlo Fedorka, Roman Buchuk, Mykhailo Klymenko, Fedir Saibert, and Andrii Petrushyn were jointly involved in the conceptualization and design of the study, the implementation of the adaptive artificial intelligence learning models, and the integration of these models into decision support systems for smart regions. They collectively contributed to the analysis and interpretation of the results and participated in drafting, reviewing, and editing the manuscript. All authors read and approved the final version of the paper.

Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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