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Integration of Intelligent Systems and "Smart City" Concept in the Context of Urban Development of Agglomerations: Methodological and Practical Aspects

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ABSTRACT

The article is devoted to the study of opportunities and methodological aspects of integrating intelligent systems (IS) in urban development of agglomerations, with a focus on the context of the Baku region of Azerbaijan. In the context of global trends of urbanization and concentration of resources in agglomerations, the concept of "smart city" is considered as a promising paradigm for solving complex problems of urban environment management and sustainable development. The article analyzes the theoretical foundations of the concept of "smart city" and the role of intelligent systems, assesses the state of urban development of Azerbaijan's agglomerations, identifies key challenges and opportunities for the application of IS in various areas, including transport, energy, security and water management. Based on the analysis, the author develops practical recommendations for the adaptation and implementation of IS in the existing urban planning practice of Azerbaijan, taking into account the unique socio-economic and geographical features of the region, aimed at improving the efficiency, safety and quality of life of citizens.

KEYWORDS: *Smart city, intelligent systems (IS), urban development, sustainable development, agglomerations of Azerbaijan, methodology of implementation.*

INTRODUCTION

The relevance of this study is determined by the persistent global trends of urbanization, characterized not only by the widespread increase in the urban population, but also by the concentration of human, economic, and infrastructural resources in large agglomerations. This process inevitably leads to more complex mechanisms for the functioning of the urban environment, an increased anthropogenic burden on infrastructure, and, consequently, an exacerbation of problems related to ensuring the efficient use of limited resources, maintaining a high level of public safety, and creating a comfortable and livable urban environment. Given the increasing complexity and dynamism of modern urban systems, the "Smart City" concept is considered a promising strategic paradigm, focused on comprehensively addressing accumulated problems through an innovative approach to management, based on the widespread application of advanced information and communication technologies and intelligent systems.

Within the context of implementing the "Smart City" concept, intelligent systems play a key role. These systems are complex, integrated sets of hardware and software tools designed for automated collection, processing, analysis, and visualization of data characterizing various aspects of urban environment functioning. These systems enable real-time monitoring, situation forecasting, well-informed management decision-making, and process optimization in critical areas such as transportation and logistics, energy and resource supply, environmental safety, housing and communal services, public safety, and emergency management. Despite the recognized potential of intelligent systems to improve the efficiency and sustainability of urban systems, the issues of their effective integration into the urban development of agglomerations — in particular, the methodological foundations, practical tools, and implementation mechanisms — remain insufficiently developed and require in-depth scientific analysis to facilitate the effective deployment and scaling of these technologies.

The existing literature on smart cities and intelligent systems covers a broad range of topics, from theoretical frameworks to practical applications. Several works explore the fundamental concepts and definitions of "smart cities," highlighting the multi-dimensional nature of this approach to urban development (Baraniewicz-Kotasińska, 2022; Toli & Murtagh, 2020). These studies emphasize that a smart city is not solely defined by technology, but also by its ability to address social, economic, and environmental challenges. Research has also focused on the specific application of intelligent systems in various urban domains. Aliyev et al. (2023) investigated the use of integrated digital technologies for transport system development in the Baku urban agglomeration. Kirimtat et al. (2020) provided a survey of future trends and the current state of smart city concepts, with a particular focus on energy-related applications. Ghosal and Halder (2018) addressed the broader issues, challenges, and approaches to building intelligent systems for smart cities, while Al-gaashani et al. (2020) examined the architecture of intelligent systems and their applications based on edge computing. These works collectively demonstrate the potential of intelligent systems to optimize various aspects of urban life.

Several publications provide valuable insights into the specific context of Azerbaijan. Badalov (2020) analyzes the demographic and socio-economic trends of Azerbaijani agglomerations. Suleymanov (2018) discusses the diversification of the Azerbaijani economy, which is relevant to the broader context of sustainable development and resource management in smart cities. The World Bank (2021) report provides a framework for analyzing and developing "smart villages" in Azerbaijan, which can offer insights applicable to smaller urban centers and the rural-urban interface. Valiyev (n.d.; 2022) directly addresses the challenges and opportunities of building smart cities in Azerbaijan, highlighting both the conceptual difficulties and the practical obstacles. The publications mentioned above, emphasize that a holistic approach is necessary, combining the implementation of advanced technologies with a thorough consideration of local specifics. However, while the existing literature provides a valuable foundation, there remains a need for a focused investigation into the methodological and practical aspects of integrating intelligent systems into the specific urban development context of Azerbaijani agglomerations. This research aims to bridge this gap by providing a comprehensive framework and practical recommendations tailored to the unique characteristics of the region.

The problem that this research addresses is the need to determine optimal and scientifically sound approaches to integrating intelligent systems into urban planning projects implemented as part of the development of modern agglomerations. An important aspect is the identification and systematization of factors that both stimulate and hinder the successful integration of intelligent systems into the urban environment. Special attention is paid to adapting existing methodological developments and best practices used in other countries to the specific conditions of urban development in agglomerations located within the territory of the Republic of Azerbaijan. Furthermore, this study aims for a comprehensive assessment of the potential application of intelligent systems in various urban planning projects being implemented in Azerbaijan, taking into account the unique socio-economic, cultural, and geographical characteristics of the region.

The goal of this research is to develop scientifically grounded methodological recommendations aimed at the effective integration of intelligent systems into the urban development of agglomerations, with an emphasis on the specific conditions and challenges facing Azerbaijan. To achieve this goal, it is necessary to address the following key objectives:

- analyze the theoretical foundations of the "Smart City" concept and intelligent systems.
- develop a comprehensive methodology for evaluating the effectiveness of implementing intelligent systems in the urban environment.
- conduct a detailed analysis of existing urban planning practices used in agglomerations in Azerbaijan.
- identify promising directions for the application of intelligent systems in specific urban planning projects being implemented in Azerbaijan.
- develop practical recommendations for adapting and implementing intelligent systems into existing urban planning practices in Azerbaijan.

METHODS AND PROCEDURE

The methodological approach involved the systematization and generalization of scholarly publications, regulatory documents, and strategic programs dedicated to the "Smart City" concept, intelligent systems, and the urban development of agglomerations (Baraniewicz-Kotasińska, 2022; Kirimtat et al., 2020; Toli & Murtagh, 2020). Particular attention was paid to studying international experiences and the most effective practices for implementing intelligent systems in urban environments (Gerdes, 2012; C40 Cities Climate Leadership Group, 2018; Government of Singapore, n.d.; Kiger P. J., 2023), as well as analyzing the theoretical foundations of intelligent system operation, including their architecture, functional components, and the artificial intelligence methods they employ (Al-gaashani et al., 2020; Ghosal & Halder, 2018). The research included an analysis of statistical data characterizing the urban development of agglomerations in Azerbaijan, specifically demographic indicators, economic structure, infrastructure condition, and the level of digitalization (State Statistical Committee of the Republic of Azerbaijan, 2016; Badalov, 2020). In addition, an analysis of existing urban planning practices, implemented projects, and the regulatory framework in the field of urban development was conducted to identify key problems and promising directions for the application of intelligent systems.

The data obtained made it possible to identify key factors influencing the effectiveness of intelligent system implementation, as well as to develop practical recommendations for adapting and integrating intelligent systems into existing urban planning practices in Azerbaijan, taking into account the unique socio-economic and geographical characteristics of the region. In developing the recommendations, methods of systems analysis and modeling were used to assess the impact of intelligent system implementation on various aspects of the urban environment, including transportation, energy, security, and water resource management.

DISCUSSION

Theoretical Foundations of the "Smart City" Concept and Intelligent Systems

The "Smart City" concept represents a multifaceted and evolving approach to urban development, based on the integration of information and communication technologies (ICT) and intelligent systems to enhance efficiency, sustainability, and quality of life within the urban environment. The history of this concept spans several decades, beginning with early attempts to automate individual city services – initially, the concept focused primarily on automating separate, isolated urban services. Examples of such initiatives include the automation of traffic flow management and the optimization of energy supply systems. In these projects, the emphasis was mainly on using technology to improve operational efficiency and reduce costs. However, over time, the understanding of the "Smart City" has evolved, and the concept has come to encompass a much wider range of aspects, including social, environmental, and economic considerations (Baraniewicz-Kotasińska, 2022; Kirimtat et al., 2020; Toli & Murtagh, 2020). This led to the realization of the need to integrate technological innovations not only with infrastructural needs but also with the needs and expectations of citizens, as well as with the goals of ensuring sustainable development. In other words, the modern approach to creating "Smart Cities" has led to the creation of complex ecosystems that unite various sectors of the economy and public life, and ensure interaction between them. This process has required not only the introduction of advanced technologies but also the development of new management models based on the principles of openness, transparency, and citizen participation.

Regarding intelligent systems (IS), they are complex cyber-physical systems with the ability to autonomously solve tasks requiring cognitive abilities, such as learning, adaptation, reasoning, and decision-making in conditions of uncertainty and incomplete information (Al-gaashani et al., 2020). They are based on the application of artificial intelligence (AI) methods, machine learning (ML), deep learning (DL), natural language processing (NLP), and other modern technologies that allow simulating the cognitive functions of human intelligence (Ghosal & Halder, 2018). A distinctive feature of IS is their ability to self-learn, adapt to dynamically changing conditions, and make proactive decisions without direct operator intervention (Kirimtat et al., 2020).

The classification of IS can be performed according to various criteria, including functional purpose, level of autonomy, architecture, and the artificial intelligence methods used. In the context of the "Smart City," IS are categorized for managing transportation systems (Intelligent Transportation Systems – ITS), energy grids (Smart Grids), security systems (Smart Security Systems), and water supply (Smart Water Management Systems) (Aliyev et al., 2023) (Table 1):

- ITS provide traffic optimization, public transportation management, and intelligent parking based on data obtained from sensors and video surveillance cameras.
- Smart Grids provide monitoring and control of energy consumption, integration of distributed generation sources, and load management based on machine learning algorithms.
- Smart Security Systems provide proactive detection and prevention of security threats based on analysis of video streams and sensory activity data.
- Smart Water Management Systems provide water quality monitoring, leak detection, and optimization of water resource distribution based on data obtained from sensors and meters.

Table 1. Classification of Intelligent Systems (IS) in a Smart City

System	Functional purpose	Architecture	AI-methods	Application examples	Technologies
ITS (Intelligent Transportation Systems)	Optimization of traffic flows, improvement of public transport efficiency, parking space management, reduction of accidents	Distributed, multi-agent, service-oriented (SOA), cloud-based	Machine learning (traffic forecasting, dynamic routing), computer vision (license plate recognition, pedestrian detection), optimization algorithms (traffic signal control, vehicle allocation)	Adaptive traffic signal control, intelligent transportation systems, Mobility-as-a-Service (MaaS) platforms, V2X (Vehicle-to-Everything) systems	5G/6G, Edge Computing, digital twins of transportation infrastructure
Smart Grids	Optimization of energy consumption, integration of RES (renewable energy sources), improvement of energy supply reliability, reduction of energy losses	Distributed, hierarchical, cyber-physical	Machine learning (load forecasting, generation optimization), multi-agent systems (distributed generation management), deep learning (smart meter data analysis)	Microgrid management, dynamic pricing, Demand Response, smart meters, predictive maintenance	IoT, Blockchain, digital twins of energy systems

Smart Security Systems	Proactive crime prevention, improvement of public safety, ensuring rapid response to incidents	Distributed, cloud-based, fog computing	Computer vision (facial recognition, anomaly detection), sensor data analysis (acoustic, vibration), natural language processing (text message analysis)	Video surveillance systems with analytics, access control systems, intrusion detection systems, threat recognition systems	AIoT, Big Data Analytics, Cybersecurity
Smart Water Management Systems	Optimization of water supply, reduction of water losses, improvement of water quality, prevention of accidents	Distributed, sensor-based, cyber-physical	Machine learning (consumption forecasting, leak detection), hydrological process modeling, optimization algorithms	Smart water meters, water quality monitoring systems, pressure management systems, leak detection and localization systems	IoT, Digital Twins, hydraulic modeling

The architecture of an IS typically includes functional components such as a Sensor Network, Data Communication Network, Data Processing Center, Decision Support System, and User Interface (Al-gaashani et al., 2020; Ghosal, Halder, 2018) (Table 2):

- The Sensor Network consists of heterogeneous sensors that measure various environmental parameters and the condition of objects.
- The Data Communication Network ensures reliable and secure data transmission from the sensors to the data processing center.
- The Data Processing Center performs preprocessing, analysis, and storage of data, as well as the training of machine learning models.
- The Decision Support System generates recommendations and automated control actions based on the results of data analysis and trained models.
- The User Interface provides interaction between the system and users, allowing them to monitor the system's status, manage its operation, and receive analytical reports.

Table 2. Architecture of Intelligent Systems (IS) in a Smart City

Functional component	Description	Technologies used	Characteristics
Sensor Network	A distributed network of heterogeneous sensors (IoT devices) that collect data on various parameters of the environment, infrastructure, and human activity.	Wireless Sensor Networks (WSN), LPWAN (LoRaWAN, NB-IoT, Sigfox), MQTT, CoAP, Edge Computing, Micro-Electro-Mechanical Systems (MEMS)	Sensor energy efficiency, data calibration and validation, ensuring security and fault tolerance of the sensor network, data heterogeneity and integration of different sensor types. Development of Edge AI, enabling preprocessing of data directly on devices, reducing the load on centralized systems.
Data Communication Network	Provides reliable, secure, and efficient data transmission from the sensor network to the data processing center and vice versa.	5G/6G, fiber optic networks, Software-Defined Networking (SDN), Network Function Virtualization (NFV), security protocols (TLS/SSL)	Requires ensuring QoS (Quality of Service) for the transmission of data with varying criticality, managing latency and bandwidth, dynamic allocation of network resources, integration with legacy systems.
Data Processing Center	Performs data aggregation, preprocessing, analysis, and storage, as well as the training and deployment of machine learning models.	Cloud Computing, Big Data platforms (Hadoop, Spark), Data Lakes, Data Warehouses, machine learning technologies (MLflow, Kubeflow), NoSQL databases, virtualization technologies	Scalability, real-time processing of large data volumes (stream processing), ensuring data integrity and security, efficient data management, and integration with other systems.
Decision Support System	Generates recommendations and automated control actions based on data analysis and trained models, using optimization, forecasting, and planning methods.	Decision Support Systems (DSS), expert systems, optimization algorithms, simulation, digital twins	Importance of interpretability of machine learning models, the ability to explain decisions made, integration with control systems, ensuring transparency and controllability of the decision-making process.

User Interface	Provides interaction between the system and users (operators, citizens, administrators), allowing them to monitor the system's status, manage its operation, and receive analytical reports.	Web interfaces, mobile applications, data visualization, Geographic Information Systems (GIS), AR/VR technologies	Focus on creating a user-friendly product with an intuitive interface, the ability to customize to individual needs, adaptation to different user categories, ensuring accessibility, and integration with other information systems.

Today, Intelligent Systems (IS) play a crucial role in the transformation of modern cities into "smart cities" (Baraniewicz-Kotasińska, 2022). They contribute to achieving sustainable development goals (Toli & Murtagh, 2020), enhance operational efficiency, ensure safety, and significantly improve the quality of life for city residents. The integration of intelligent systems into various domains of urban life, from energy resource management to public safety, not only optimizes the use of existing resources but also creates new opportunities for economic growth and social progress (Valiyev, A., n.d.). This transformation is based on the ability of IS to analyze vast amounts of data from various sensors and devices, identify patterns and dependencies, and, based on the information obtained, make informed decisions aimed at optimizing processes and improving services (Al-gaashani et al., 2020).

Improving resource efficiency is one of the most significant outcomes of implementing IS. This is achieved through the application of sophisticated optimization algorithms based on machine learning and artificial intelligence, which significantly reduce energy consumption, decrease greenhouse gas emissions, and optimize the use of other resources (Kirimtat et al., 2020). For example, intelligent energy management systems not only track energy consumption in real-time but also forecast demand, automate switching processes between different energy sources (including renewables), and optimize the operation of power grids. In Copenhagen, Denmark, the city's district cooling system uses harbor water to cool buildings. An intelligent control system optimizes the distribution of chilled water based on the harbor water temperature and the cooling needs of buildings (Gerdes, 2012). When the harbor water temperature is below 5.5°C (41.9°F), the system uses "free cooling" via heat exchangers (Gerdes, 2012). At higher water temperatures, chillers are used, but the system optimizes their operation to minimize energy consumption, resulting in an 80% reduction in electricity consumption and a 67% reduction in carbon dioxide emissions compared to traditional cooling systems. It also frees up space on rooftops and in basements where compressors and cooling towers were previously located (Gerdes, 2012).

IS for traffic management reduce travel time, alleviate congestion, and decrease air pollution by optimizing public transport routes, adaptively controlling traffic signals, and providing real-time traffic information (Aliyev et al., 2023). Barcelona, Spain, is implementing a "Superblocks" program aimed at reorganizing urban spaces, prioritizing pedestrians and public transport (C40 Cities Climate Leadership Group, 2018). As part of this program, streets are being redesigned to reduce through-traffic and increase green spaces. Intelligent systems are used to monitor traffic flows, adaptively manage traffic signals, and optimize public transport routes. This program, combined with the Urban Mobility Plan, has reduced the use of private cars and mopeds in the city by 21%, and the city aims to reduce CO_2-equivalent emissions per capita by 40% by 2030 compared to 2005 levels (C40 Cities Climate Leadership Group, 2018).

IS for water resource management, in turn, ensure optimization of water consumption, detection and prevention of leaks, water quality control, and efficient distribution of water resources among different users. In Singapore, where water supply is a particularly acute issue, the NEWater system has been developed and implemented, using advanced technologies to recycle treated wastewater into ultra-clean, high-quality water (Government of Singapore, n.d.). The NEWater process includes microfiltration/ultrafiltration, reverse osmosis, and ultraviolet disinfection (Government of Singapore, n.d.). The system is managed by intelligent systems that optimize each stage of the recycling process to ensure compliance with the strictest drinking water quality standards set by the WHO and the US Environmental Protection Agency (Government of Singapore, n.d.). NEWater has become an important part of Singapore's water strategy, reducing dependence on water imports and ensuring a sustainable water supply.

Similarly, IS for waste management optimize waste collection and recycling, reduce the volume of waste sent to landfills, and increase the proportion of recycled materials by optimizing waste collection routes, automating sorting, and monitoring the fullness of containers. In Stockholm, Sweden, a sophisticated waste management system is in place, which requires citizens by law to sort their waste. IS are used to optimize collection routes, automate sorting, and monitor container fill levels (Kiger P. J., 2023). Sweden recycles or composts more than half of its household waste, and much of the remaining waste is incinerated at waste-to-energy plants that provide heat to 1.2 million Swedish homes and electricity to another 800,000 (Kiger P. J., 2023).

Ensuring security and public order is another important area of application for IS in smart cities (Ghosal & Halder, 2018). Modern video surveillance systems, equipped with facial recognition algorithms and behavioral pattern analysis, can identify suspicious activity and prevent crime. Predictive policing systems, using data on previous crimes, social conditions, and other factors, predict the occurrence of crimes and direct law enforcement resources to the most problematic areas. Intelligent emergency management systems provide rapid response to incidents, coordinate the actions of various services, and inform the public about potential threats. Furthermore, IS play a vital role in ensuring the cybersecurity of urban infrastructure, protecting it from cyberattacks and ensuring the reliable operation of critical systems.

Improving the quality of life for city residents is achieved through the application of IS in other areas as well, including healthcare, education, transportation, and housing and utilities. Telemedicine systems provide medical consultations and monitor patients' health remotely, ensuring access to quality healthcare even in remote areas. Interactive educational platforms provide personalized learning and improve student performance by adapting learning materials and teaching methods to the individual needs and abilities of each student. Intelligent transportation systems, as previously mentioned, reduce travel time and improve the comfort of movement (Aliyev et al., 2023), while intelligent systems for managing housing and utilities improve service quality and reduce utility costs.

Stimulating economic development is an indirect but important result of implementing IS. Smart cities become more attractive to investment and skilled professionals, creating a favorable environment for the development of innovative companies and the creation of new jobs in the ICT sector and innovative technologies (Suleymanov, 2018). The development of new business models and services based on data and machine learning algorithms contributes to increasing the city's competitiveness in the global market. Thus, the implementation of IS in smart cities not only improves the quality of life and ensures safety but also creates a sustainable economy (World Bank, 2021).

RESULT

Analysis of Urban Development in Azerbaijan's Agglomerations and the Potential for Applying Intelligent Systems

Azerbaijan, and particularly the Baku Agglomeration (BA), is currently at an important stage of urban development. Having undergone a period dominated by economic dependence on the oil and gas industry, the country is taking active steps to diversify its economy and integrate modern technologies into various aspects of society. Currently, there is active development in manufacturing industries such as mechanical engineering, electrical engineering, light industry, agriculture, and the service sector (Badalov, 2020). The development of the non-oil sector is based on the creation of industrial parks and special economic zones. These processes have influenced labor migration and the intensity of traffic flows, and have also expanded the boundaries of the agglomeration to a one-and-a-half-hour commute — within these boundaries, the number of satellite cities has increased to 7, and the population has reached 3 million people (Badalov, 2020). Unofficial estimates, which take into account unregistered migration and temporary residence, indicate a significantly larger actual population of the agglomeration, exceeding 5 million people, including more than 500,000 refugees and internally displaced persons (Badalov, 2020).

However, the development of "smart cities" in Azerbaijan is a multifaceted process with both significant potential and serious challenges. Successful implementation of the "smart city" concept requires not only the introduction of advanced technologies but also a deep understanding of the socio-economic, cultural, and geographical characteristics of the region, as well as the development of a comprehensive strategy that takes these characteristics into account. Although the government has expressed its commitment to the development of "smart cities," achieving the set goals is only possible if a number of critical barriers are overcome and key areas are purposefully developed.

Table 3. Analysis of Urban Development in Azerbaijani Agglomerations and the Potential for Applying Intelligent Systems (IS)

Aspect	Qualitative Analysis	Potential of IS
Geopolitics	Key role as a transport corridor (North-South, East-West) dictates the priority of infrastructure development and economic diversification. Adaptation to geopolitical instability is necessary.	Geopolitical risk assessment using geospatial analysis.
Sustainable City	Priority is sustainable development (ecology, social equity, economic viability). Land use planning, transport accessibility, and social housing are important.	Land use optimization systems (GIS, BIM), transportation management (smart networks), energy efficiency (BEMS), environmental monitoring.
Digital Divide and Data	Gap in internet access (city-regions, urban-rural), insufficient digital literacy. Shortage of specialists in Data Science and IoT. Data issues (quality, openness).	Development of communication infrastructure, increasing digital literacy, training specialists, open data policy, cybersecurity.
Finance and Investment	Dependence on oil and gas, price volatility. Diversification of funding sources and improvement of the investment climate are needed.	Economic diversification, improvement of the investment climate (transparency, protection of rights), PPPs, green bonds.

Socio-economic Inequality	Concentration of resources in Baku. Regional development strategies are needed.	Regional strategies, investment in regions, support for SMEs, monitoring and evaluation of development.
Urbanization and Migration	High level of urbanization. Housing planning and development of the transportation system are necessary.	Traffic flow management (ITS), urban planning, pollution monitoring.
Infrastructure	Modernization of transport, energy, and utility infrastructure.	ITS, energy consumption management (Smart Grid, BEMS), water resource management, waste management.

One of the main obstacles on the path to a "smart" future is the existing digital divide between urban and rural areas. Limited access to high-speed internet, low levels of digital literacy (especially in rural areas), and insufficient development of digital infrastructure (ADB, 2018) significantly hinder the implementation and effective use of "smart city" technologies (Table 3). This gap not only limits the ability to collect and analyze the data needed for informed decision-making in urban management but also hinders the full participation of citizens in decision-making processes and access to e-services. As A. Valiyev (2022) notes, the existing 20 percent gap in fixed internet penetration between urban and rural households creates a serious obstacle to building truly inclusive "smart cities." Overcoming this gap requires significant investments in the development of digital infrastructure, educational programs to increase digital literacy, and the formation of a culture of active use of digital technologies.

Financial constraints and an underdeveloped innovation potential represent another significant challenge. The implementation of "smart city" projects requires significant capital investments in infrastructure, technology, and human capital development (World Bank, 2021). Attracting private investment is a key success factor, but existing barriers in the investment climate, including insufficient investment protection, underdeveloped financial markets, and difficulties in doing business, hinder private sector activity (Valiyev, 2022). Furthermore, the low level of innovation activity, the lack of qualified personnel in the fields of data analysis, artificial intelligence, and the management of intelligent technologies require the development of long-term programs to develop human capital and stimulate innovation.

Significant socio-economic inequality between Baku and other regions of Azerbaijan represents an additional challenge for the implementation of the "smart city" concept (World Bank, 2021). The concentration of resources and investments in the capital may exacerbate this inequality and create a situation where the benefits of "smart" technologies are available only to a limited number of citizens. The development of differentiated "smart city" development strategies that take into account the specifics of each region is a prerequisite for ensuring balanced and inclusive development. However, realizing this potential requires a comprehensive approach that includes not only the introduction of technological innovations but also the development of human capital, governance reform, and ensuring equal access to resources for all residents of the region. We will analyze the areas of development in more detail, supporting the recommendations with justifications derived from the analysis of the current situation.

Practical Recommendations for Adapting and Implementing IS in Azerbaijan's Existing Urban Development Practices

Intelligent Transportation Systems (ITS)

Implementing ITS is one of the most pressing areas, given the problem of traffic congestion and the insufficient efficiency of public transport in Baku. To achieve maximum impact, the implementation of Adaptive Traffic Control Systems (ATCS) using machine learning (ML) algorithms is recommended. These systems, receiving information from traffic sensors (video cameras, vehicle detectors), dynamically adjust traffic signal cycles in real-time, optimizing intersection throughput and reducing vehicle delays.

The implementation of these systems should take into account real-time traffic data, information on road works, weather conditions, and accident data. To increase the system's efficiency, it is advisable to use V2X (Vehicle-to-Everything) systems, allowing data exchange between vehicles, road infrastructure, and other road users. This will, for example, warn drivers of potential hazards, optimize routes, and reduce accidents. Special attention should be paid to the creation of intelligent parking management systems. The implementation of parking space occupancy sensors, online reservation systems, dynamic pricing, and navigation applications that guide drivers to available parking spaces will reduce traffic caused by searching for parking and increase convenience for drivers. License plate recognition, combined with integration with payment systems, will simplify the parking payment process.

Given the limited parking spaces in the central part of Baku, it is advisable to consider the construction of multi-level parking garages and the use of technologies to optimize the use of existing spaces. In parallel, intelligent public transport management systems should be developed, including monitoring systems (GPS), route planning (taking into account traffic and passenger flow), and passenger information (in real-time). Such systems will increase the attractiveness of public transport and contribute to reducing the use of private cars.

Smart Grids

The implementation of "smart" energy grids (Smart Grids) is critically important for improving energy efficiency, reducing dependence on fossil fuels, and achieving sustainable development goals. The implementation of smart electricity meters is recommended, providing real-time consumption monitoring and enabling the implementation of differentiated tariffs based on time of day and grid load. This data will allow consumers to manage their energy consumption more effectively, and energy companies to optimize electricity distribution.

Furthermore, it is necessary to encourage the integration of distributed generation sources (renewable energy sources, microgeneration), such as solar panels and wind turbines. Smart Grids will allow the integration of these sources into the overall grid, ensuring the stability of energy supply and reducing greenhouse gas emissions. The implementation of dynamic load management systems based on ML algorithms is recommended, which will balance electricity supply and demand, optimize grid operation, and reduce losses. The use of Demand Response (DR) systems will allow managing electricity consumption depending on current needs and tariffs, contributing to reducing peak loads on the power system.

For the effective functioning of Smart Grids, it is necessary to create data centers that collect, store, and analyze information from sensors and meters. It is necessary to develop and implement models for forecasting electricity consumption and generation, and also to pay special attention to ensuring the cybersecurity of energy grids.

Smart Security Systems

The development of Smart Security Systems is aimed at proactively preventing crime, increasing the level of public safety, and ensuring rapid response to emergencies. To achieve these goals, the widespread use of modern video surveillance systems with analytics is recommended. The systems should include facial recognition algorithms, behavioral pattern analysis (e.g., detection of suspicious movements, abandoned objects, fights), and anomaly detection. The application of AIoT (Artificial Intelligence of Things) will allow the integration of data from various sensors (acoustic, vibration, air pollution sensors) for the proactive detection of threats, such as earthquakes or explosions. The implementation of predictive policing systems, using data on previous crimes, socio-economic factors, and other parameters, will allow forecasting the occurrence of crimes and directing law enforcement resources to the most problematic areas. This will increase the efficiency of law enforcement and reduce crime rates. It is necessary to implement intelligent emergency management systems that ensure rapid response to incidents (fires, floods, accidents), coordinate the actions of various services (police, fire, ambulance), and inform the public about potential threats. Particular attention should be paid to ensuring the cybersecurity of these systems to prevent unauthorized access and data manipulation.

Smart Water Management Systems

Given the limited water resources and the need to improve their efficient use, the implementation of Smart Water Management Systems is critically important. The implementation of smart water meters (for consumption monitoring) is necessary, allowing consumers to monitor their water consumption and promptly detect leaks. It is necessary to develop water quality monitoring systems that provide real-time control over the quality of drinking water. These systems will enable the prompt detection of contamination and the taking of measures to ensure the safety of water supply. The implementation of leak detection systems (using machine learning to analyze data from sensors and predict consumption) in water supply networks is recommended. The use of digital twins of hydraulic networks will allow optimizing the distribution of water resources, predicting the occurrence of accidents, and developing strategies to prevent them. Digital twins can be used to simulate various scenarios, such as droughts or floods.

For the successful implementation of the "smart city" strategy, a comprehensive plan is needed, taking into account the specific development characteristics of Baku and other regions. The plan should include: defining priority areas based on an analysis of current problems and needs; developing feasibility studies (FS) that assess the viability of implementing specific solutions; and conducting pilot projects that allow assessing the effectiveness of proposed technologies and gaining experience in their implementation. It is important to develop and use a unified geographic information system (GIS) platform that provides integration of data from various systems (ITS, Smart Grids, Smart Security Systems, Smart Water Management Systems), data visualization, and tools for informed decision-making. To ensure maximum effectiveness, it is recommended to integrate IS with existing city management systems (e.g., planning and budget management systems) and provide for their further development and scalability.

CONCLUSION

In summary, this study has demonstrated that the integration of intelligent systems into the urban development of agglomerations, particularly the Baku Agglomeration, represents not only a promising direction but also an objective necessity in the face of modern urbanization challenges. The "smart city" concept, based on the widespread application of information and communication technologies and intelligent systems, provides unique opportunities to improve the efficiency of urban environment management, optimize resource utilization, ensure security, and ultimately, significantly improve the quality of life for city residents. However, as the analysis has shown, the successful implementation of this concept requires a comprehensive and systematic approach that takes into account not only technological aspects but also the socio-economic, cultural, and geographical characteristics of the region. The implementation of intelligent systems should not be an end in itself, but rather a tool for solving specific problems and challenges facing Azerbaijan's agglomerations. A crucial condition is the development of a clear strategy based on a thorough analysis of the current situation, identification of priority areas, and phased implementation of the most effective solutions.

The analysis of the current state of urban development in Azerbaijan's agglomerations, particularly the Baku Agglomeration, has revealed a number of key problems and challenges that can be effectively addressed through intelligent systems. The problems of traffic congestion, inefficient use of energy and water resources, public safety, and environmental sustainability require the application of innovative approaches and technologies. At the same time, the existing digital divide, financial constraints, insufficient innovation potential, and socio-economic inequality between regions create certain obstacles on the path to a "smart" future. Overcoming these barriers requires not only investment in infrastructure and technology but also the development of human capital, reform of the governance system, and the creation of a favorable investment climate. An important aspect is ensuring equal access to the benefits of "smart" technologies for all citizens, regardless of their location and income level. This requires the development of differentiated "smart city" development strategies that take into account the specifics of each region and are aimed at creating an inclusive and sustainable urban environment.

The practical recommendations presented in this work for adapting and implementing intelligent systems in Azerbaijan's existing urban development practices, covering key areas such as transportation (ITS), energy (Smart Grids), security (Smart Security Systems), and water resource management (Smart Water Management Systems), are aimed at solving specific problems and achieving measurable results. The recommendations are based on an analysis of best international practices, adapted to the specific conditions of Azerbaijan, and involve the use of advanced technologies such as artificial intelligence, machine learning, the Internet of Things, and digital twins. The implementation of the proposed solutions will not only improve the efficiency of urban environment management but also create new opportunities for economic growth, stimulate innovation, and improve the quality of life for city residents. Further research in this area should be directed towards developing more detailed technical specifications, conducting pilot projects, and assessing the long-term socio-economic impact of implementing intelligent systems in the urban development of Azerbaijan's agglomerations.

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