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BIG DATA IN EFFECTIVE MANAGEMENT OF INTELLECTUAL CAPITAL OF COMPETITIVE ENTERPRISES IN PUBLIC SECTOR OF ECONOMY UNDER CRISIS CONDITIONS

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Abstract. *The development of the public sector of the economy increasingly takes place under conditions of heightened instability caused by economic crises, geopolitical shocks, institutional transformations, and accelerated digitalization. In such an environment, intellectual capital becomes a key strategic resource determining the sustainability and competitiveness of state-owned enterprises. Traditional approaches to intellectual capital management in the public sector are often inertial and formalized, which significantly limits their effectiveness in crisis conditions.*

This study substantiates the relevance of integrating Big Data technologies into the adaptive management of intellectual capital of public sector enterprises. The research is based on the concepts of intellectual capital, digital transformation, systems analysis, and applied data analytics. General scientific methods, economic-statistical analysis, and a systems approach are employed to examine human, structural, and relational capital as interrelated components of a complex socio-economic system.

The paper demonstrates that Big Data technologies enable the processing and analysis of large volumes of heterogeneous structured and unstructured data in near real time, allowing the identification of hidden patterns, prediction of risks, and proactive decision-making. The application of intelligent analytics, machine learning, and predictive models enhances transparency, supports strategic planning, and improves the allocation of limited intellectual resources in crisis environments.

The findings confirm that Big Data-based management models significantly increase the adaptability and innovative capacity of public sector enterprises, contributing to their long-term sustainability and competitive performance. The study emphasizes the necessity of methodological

adaptation, organizational readiness, and the development of digital competencies for the effective implementation of Big Data solutions in the public sector.

***Key words**: Big Data, intellectual capital, public sector enterprises, digital transformation, crisis conditions, instability, efficiency, competitiveness*

Introduction.

The modern economy is developing under high turbulence - geopolitical events, financial crises, pandemics and technological changes create significant uncertainty [1-3]. The acceleration of global transformation processes and the growth of crisis phenomena of various nature form fundamentally new conditions for the functioning of socio-economic systems. Geopolitical shocks, financial crises, pandemics and technological changes create a high level of uncertainty, which significantly affects the efficiency of management processes [4-6]. Thus, in the above-mentioned modern complex conditions, ALL enterprises are faced with a constantly changing economic, political and social environment.

It is the enterprises of the public sector of the national economy in such conditions that act NOT only as business entities, but as institutional stabilizers that ensure the continuity of critically important services and infrastructures. The effectiveness of the implementation of these functions directly depends on the ability of organizations to preserve, reproduce and develop their own intellectual capital. It is the public sector that usually ensures the stability of critically important sectors of the national economy [7], but it is in this sector that traditional, conservative methodologies and technologies of anti-crisis management often turn out to be insufficiently effective [8, 9].

That is, in the above-mentioned difficult circumstances, traditional (NON-innovative) management methods are usually not flexible enough, since they are not always able to respond promptly to the changes taking place and take into account complete information about the resources and processes of the organization [10], including intellectual capital.

Intellectual capital is a set of intangible assets that form the basis of organizational development and managerial stability. In its structure, human capital is traditionally distinguished, reflecting the knowledge and competencies of personnel, structural capital, including regulations, processes and information systems, as well as relationship capital (communication), which characterizes the stability of relations with

external stakeholders. It is intellectual capital, which includes the knowledge and skills of employees (human capital), organizational procedures and corporate systems (structural capital) and external relations with partners, the public and state institutions (relational capital), that plays a key role in the competitiveness and sustainability of state-owned enterprises in unstable conditions, especially crisis conditions. In crisis conditions, these elements are at increased risk of degradation due to personnel losses, fragmentation of knowledge and disruption of management circuits. For its optimal use, a comprehensive approach is required [11], which allows not only to take into account available resources, but also to identify hidden opportunities, predict risks and support innovative development. The practice of intellectual capital management in the public sector, as before, largely relies on inertial and formalized assessment tools that do not ensure timely detection of negative trends. In this regard, the use of big data technologies, which allow processing significant amounts of heterogeneous information and generating analysis and analytics results in a mode close to real time, becomes particularly relevant [12]. At the same time, the implementation of Big Data in the public sector requires methodological adaptation, taking into account regulatory, ethical and organizational constraints.

The authors argue that it is the proposed comprehensive innovative methodology and intelligent Big Data technologies that provide new opportunities for optimal management of intellectual capital in difficult conditions. Big data technologies allow us to move from formal knowledge accounting to in-depth analysis and proactive analytics, including predictive analytics [13]. In particular, it is intelligent Big Data analysis and analytics technologies that allow us to combine different sources of information, process large volumes of data in real time, identify hidden patterns [14] and predict trends in the development of the organization [15]. Big Data processing, analysis and analytics tools help state-owned enterprises make more informed decisions, optimize resource allocation, form a personnel reserve and increase the efficiency of processes in conditions of crisis situations and instability.

Thus, the relevance of the main goal of this study is substantiated above: the development of a theoretically grounded and practically oriented approach to the

optimal use of Big Data for adaptive management of intellectual capital of state-owned enterprises in conditions of crisis instability.

Analysis of recent research and publications.

At the first stage of the analysis of publications (as part of this study), the authors carefully analyzed relevant scientific publications over the past 5 years on the use of Big Data technology in the public sector of the economy.

In particular, in the sources Pencheva et al. (2020) [16], Tiguint (2021) [17], Rahmanto et al. (2021) [18], Kokh et al. (2021) [19], Overton et al. (2022) [20] their authors focused on the macro level of Big Data implementation: transformation of public administration, formation of digital policy and transition to the concepts of Government 4.0 / State 4.0. The authors emphasize that Big Data is becoming not only a tool for increasing efficiency, but also a new logic of decision-making that affects public value, transparency and interaction with citizens. Considerable attention is paid to the challenges: ethical aspects, regulatory restrictions and inequality of access to data.

The scientific works of Okuyucu & Yavuz (2020) [21], Hamzah et al. (2020) [22], Srinavin et al. (2021) [23], Abdulrahim et al. (2025) [24], Talib et al. (2024) [25] analyze the level of readiness of government agencies to use Big Data, including institutional maturity, human resources competencies and technological infrastructure. The proposed maturity models allow assessing the progress of government organizations and identifying "bottlenecks". It is shown that the presence of technologies does not guarantee success without the development of analytical skills, change management and interdepartmental coordination.

The publications of Merhi & Bregu (2020) [26], Kim (2020) [27], Hong et al. (2022) [28], Guenduez et al. (2020) [29] focus on the connection between Big Data and public administration performance. The positive impact of data analytics on service quality, citizen satisfaction and innovative activity of authorities is proven. At the same time, the role of managerial perception and organizational culture is emphasized: without management support, Big Data often remains a declarative initiative.

Sources Lazarevska et al. (2022) [30], Saud et al. (2025) [31], Nagirikandalage et

al. (2025) [32] demonstrate the potential of Big Data to increase the transparency of financial control, audit efficiency and budget planning, especially in crisis and pandemic conditions. Big data analytics allows moving from retrospective control to proactive risk identification, which is critical for the financial sustainability of the public sector.

Sources Coulthart & Riccucci (2022) [33], Zekić-Sušac et al. (2021) [34], Loukis et al. (2020) [35], Marty & Duhaut (2024) [36] - illustrate the practical value of Big Data through specific cases: border security, energy efficiency, anti-crisis economic regulation, global poverty assessment. Research confirms that industry specifics significantly affect the architecture of analytical systems and the results of their implementation.

The works of Heeks et al. (2021) [37] and Di Vaio et al. (2022) [38] - reveal a critical dimension of Big Data - issues of power, asymmetry of access to data, social consequences and human-AI interaction. It is shown that Big Data in the public sector can simultaneously create value and increase inequalities if there are no appropriate mechanisms of governance and ethical control.

Thus, the first set of relevant sources analyzed above demonstrates that Big Data in the public sector of the economy is a multidimensional phenomenon that encompasses strategic, organizational, technological, and socio-economic aspects. The greatest effectiveness of Big Data is provided by the synergy of technologies, managerial competencies, and institutional maturity, especially in times of crisis and instability.

In the second stage of the analysis of current publications (as part of this study), the authors carefully analyzed relevant scientific publications over the past 5 years on the use of Big Data technology in intellectual capital management.

The conceptual and theoretical foundations of the integration of Big Data and intellectual capital are explored in the publications of Chiucchi et al. (2021) [39], Assi (2024) [40], Alomari et al. (2020) [41], Mahmood & Mubarik (2020) [42], Lao & Zhou (2021) [43]. These authors consider Big Data as a complementary resource to human, structural and relational capital, which enhances value creation mechanisms. Special

emphasis is placed on digitalization, smart technologies and the ability of organizations to combine knowledge, data and technological absorption in the context of Industry 4.0.

Big Data as a moderator or mediator of the impact of intellectual capital on performance has been studied in the works of Al-Khatib (2022) [44], Pilatin (2024) [45], Chen & Chen (2022) [46], Wang et al. (2023) [47], Nejjari & Aamoum (2021) [48]. It has been proven that intellectual capital alone does not guarantee high efficiency without analytical capabilities for processing big data. Big Data enhances the ability of organizations to transform knowledge into measurable

Intellectual capital, Big Data and innovative and competitive capabilities have been systematically analyzed in the publications of Alkhatib & Valeri (2024) [49], Gravili et al. (2021) [50], Lee et al. (2025) [51], Yang et al. (2024) [52]. This group of publications focuses on the innovative and strategic effects of integrating Big Data and intellectual capital. Research shows that the analytical capabilities of big data enhance the impact of intellectual capital on service innovation, international expansion, and sustainable open innovation. The combination of big data with human and relational capital in knowledge-based sectors (healthcare, international business, natural resources) is especially important.

In scientific publications AL-Khatib & Shuhaiber (2022) [53], Rehman et al. (2024) [54], Turi et al. (2023) [55] Big Data is considered as a catalyst for the implementation of green intellectual capital. The analytical capabilities of big data allow for more effective integration of environmental knowledge into supply chains, project management, and sustainable innovation. The authors argue that without Big Data green intellectual capital has limited impact on environmental and operational performance.

The next group of analyzed studies Noreña Chávez & Thalassinos (2023) [56], Dehbi (2021) [57] – cover in detail the role of Big Data in activating knowledge processes, knowledge exchange and project success. Intellectual capital in such models often acts as a mediator between Big Data and performance results. Particular attention is paid to social knowledge networks and interaction analytics (SNA).

The assessment and measurement of intellectual (primarily human) capital based on Big Data was carried out in the work of Nicolaescu et al. (2020) [58]. This study demonstrates the capabilities of Big Data analytics for quantifying human capital in knowledge-based organizations. It is shown that traditional approaches to measuring intellectual capital are significantly enhanced by the use of large data sets and machine learning.

The authors also analyzed the review publication Pringgabayu et al. (2023) [59] - which systematizes the relationships between Big Data and intellectual capital.

Therefore, the second set of scientific publications analyzed above shows that Big Data is a key amplifier of intellectual capital management, transforming knowledge into measurable economic and innovative value. The greatest effect is achieved when Big Data analytics is integrated with human, structural and green intellectual capital within the framework of a holistic management strategy.

Taking into account the above analysis of BOTH clusters of current and relevant scientific publications, it can be unequivocally stated that a synergistic complex of scientific and practical issues regarding the optimal methodology and technologies of Big Data for adaptive management of intellectual capital of public sector enterprises in difficult conditions of crisis instability (for example, in the current military, geopolitical, regional and local crisis conditions of Ukraine) remains unstudied/researched.

The aim of this study.

Therefore, taking into account the above, the main goal of this study is to improve the methodology and further develop specialized, targeted Big Data intellectual technologies specifically for the effective management of the intellectual capital of state-owned enterprises. In particular, it also identifies a set of scientific and practical aspects of their integration to increase the adaptability and competitiveness of the public sector of the national economy, taking into account uncertainties or crises.

Materials and methods.

The methodological basis is made up of the concepts of intellectual capital, digital transformation of the public sector, systems analysis and applied data analytics. The

work uses a set of methods, including both general scientific and special approaches.

General scientific methods include analysis and synthesis to reveal the structure of intellectual capital, induction and deduction to formulate conceptual provisions, abstraction and formalization when building a management model.

The systems approach considers a state-owned enterprise as a complex socio-economic system where human, structural and relational capitals interact. This justifies the need for comprehensive application of Big Data, oriented across all levels of intellectual resource management.

Economic and statistical methods were used to analyze the dynamics of human potential, innovative activity and assess the effectiveness of management decisions. Comparative analysis allowed us to compare traditional and data-driven approaches.

Particular attention was paid to regimes, methods and hyperparameters/parameters for processing, analyzing and analytics of big data - in order to identify hidden patterns and assess the management potential of state-owned enterprises in an unstable, especially crisis environment.

Main text. The modern development of the public sector of the economy takes place in conditions of increased instability, caused by economic crises, geopolitical factors, institutional transformations and accelerated digitalization of management processes. In such an environment, the key factor for the stability and competitiveness of state-owned enterprises is not so much the material base as intellectual capital, which accumulates knowledge, professional competencies, managerial experience and social ties.

Practice shows that traditional approaches to intellectual capital management in the public sector often do not take into account the dynamics of the environment and are limited to formal indicators of staffing. In conditions of crisis, such inertia leads to a decrease in the effectiveness of management decisions and the loss of critically important knowledge. In this, the role of adaptive management models based on the use of big data methodologies and technologies increases.

The methodological apparatus of Big Data allows us to consider intellectual capital as a dynamic, multi-component system, sensitive to changes in the economic

and social environment. The use of system and process approaches makes it possible to analyze not only the quantitative parameters of intellectual resources, but also their qualitative characteristics, including the degree of personnel involvement, the intensity of knowledge exchange and innovative activity. A cognitive approach focused on identifying hidden relationships and behavioral patterns in the organizational environment is of significant importance.

Big data technologies find practical application in the analysis of arrays of heterogeneous information formed in the activities of state-owned enterprises. This includes both structured data (personnel statistics, performance indicators) and unstructured sources - report texts, internal communications, expert opinions. The use of methods of intelligent data analysis, machine learning and predictive analytics allows for a more accurate assessment of the state of human and structural capital, as well as identifying potential risks of knowledge loss in crisis conditions.

Big Data is of particular importance in the context of adaptive management. Unlike rigidly defined management models, adaptive systems involve constant adjustment of decisions based on current data and scenario analysis. This allows state-owned enterprises to respond quickly to environmental changes, reallocate intellectual resources and form sustainable anti-crisis strategies. Analytical tools of big data are not an auxiliary, but an integrated element of the management process.

The introduction of Big Data technologies in intellectual capital management contributes to increasing the transparency of the activities of public sector enterprises, improving the quality of strategic planning and more rational use of limited resources. However, this process is associated with a number of limitations, including problems of data reliability, cybersecurity, as well as insufficient readiness of personnel to use digital analytical tools. Overcoming these barriers requires an integrated approach that combines technological solutions with the development of digital competencies and institutional mechanisms for supporting innovation.

Below is the analytical table, systematically presenting Big Data methodologies and technologies for crisis (anti-crisis) management of intellectual capital in the public sector of the economy.

Table 1 - Big Data Methodologies and Technologies for Crisis Management of Intellectual Capital in the Public Sector

Big Data methodology and technology	Core essence and tools	Intellectual capital component	Crisis management function	Expected effect for the public sector
Data Mining and Knowledge Discovery	Pattern detection, clustering, association rules	Human, structural	Identification of competency gaps and bottlenecks	Improved managerial decisions
Machine Learning (ML)	Predictive and classification models	Human, structural	Forecasting skill shortages	Reduced knowledge loss risks
Predictive Analytics	Scenario and risk forecasting	Human, relational	Proactive resource management	Higher adaptability
Text Mining and NLP	Analysis of unstructured text data	Structural, relational	Monitoring knowledge and sentiments	Preservation of critical knowledge
Social Network Analysis (SNA)	Analysis of professional networks	Human, relational	Identification of key experts	Stronger knowledge networks
Real-time Analytics	Streaming data processing	Structural	Operational decision adjustment	Rapid crisis response
Hybrid Big Data Analytics	AI + statistical integration	All components	Advanced decision support	Higher forecast accuracy
Decision Support Systems (DSS)	Big Data-driven decision platforms	Structural	Crisis scenario planning	Evidence-based strategies
HR Analytics	Workforce and competency analytics	Human	Crisis HR management	Optimized staffing
Data Visualization & Dashboards	Visual analytics tools	Structural	Strategic monitoring	Increased transparency
Scenario Modeling & Stress Testing	Simulation of crisis conditions	All components	Resilience assessment	Risk reduction
Big Data-enabled KMS	Integrated knowledge platforms	Human, structural	Knowledge preservation	Institutional continuity

Source: Developed by authors

The analysis (presented above in Table 1) demonstrates that Big Data methodologies and technologies constitute a comprehensive toolkit for crisis management of intellectual capital in the public sector. Their application enables a shift from reactive to adaptive and proactive management models, which is particularly critical under conditions of instability and crisis. The greatest effectiveness is achieved through the hybrid integration of advanced analytics, organizational maturity, and digital competencies of personnel, ensuring the long-term sustainability and competitiveness of public sector enterprises.

Table - Big Data Tools and Instruments for Crisis Management of Intellectual Capital in the Public Sector of the Economy

Big Data tool / instrument	Functional purpose	Data type	Intellectual capital compo-nent	Crisis management role	Practical effect for the public sector
Apache Hadoop (HDFS, MapReduce)	Distributed storage and processing of large-scale datasets	Structured / unstructured	Structural	Resilience of analytical infrastructure	Reliable processing under crisis conditions
Apache Spark	High-speed in-memory data processing	Streaming / batch	Structural	Real-time decision support	Faster crisis response
Machine Learning Libraries (MLlib, Scikit-learn)	Predictive and classification modeling	Analytical	Human	Forecasting skill gaps and turnover	Reduced knowledge loss
Natural Language Processing (NLP)	Analysis of texts and communications	Unstructured	Structural, relational	Detection of hidden problems and knowledge	Preservation of institutional memory
Text Mining Platforms	Semantic analysis of documents	Documentary	Structural	Monitoring knowledge changes	Managerial stability
HR Analytics Systems	Workforce and competency analytics	Structured	Human	Crisis-oriented HR management	Optimized staffing decisions
Social Network Analysis Tools (Gephi, NodeXL)	Analysis of knowledge networks	Graph-based	Human, relational	Identification of key experts	Knowledge resilience
Predictive Analytics Platforms	Risk and scenario forecasting	Analytical	All components	Proactive crisis management	Higher adaptability
Decision Support Systems (DSS)	Analytics-integrated decision-making	Integrated	Structural	Crisis strategy development	Evidence-based decisions
Business Intelligence (BI) Tools	Aggregation and visualization of analytics	Structured	Structural	Strategic monitoring	Governance transparency
Dashboards and Data Visualization	Visualization of KPIs and IC indicators	Analytical	Structural	Monitoring critical indicators	Early crisis detection
Knowledge Management Systems (KMS)	Knowledge capture and dissemination	Mixed	Human, structural	Prevention of knowledge loss	Institutional continuity
Cloud-based Big Data Platforms	Scalable analytics infrastructure	All types	Structural	Managerial flexibility	Cost optimization

Big Data tool / instrument	Functional purpose	Data type	Intellectual capital compo-nent	Crisis management role	Practical effect for the public sector
Hybrid AI-based Analytics	AI + statistical integration	Analytical	All components	Decision-making under uncertainty	Higher forecast accuracy
Cybersecurity and Data Governance Tools	Data protection and access control	All types	Structural, relational	Trust and compliance assurance	Process stability

Source: Developed by authors

Below is the author's analytical table of relevant Big Data tools and means that are appropriate to use for optimal anti-crisis management of intellectual capital in the public sector of the economy.

The Big Data tools and tools (presented in Table 2) form an integrated anti-crisis infrastructure for intellectual capital management in the public sector. Their application allows not only to respond promptly to crisis challenges, but also to move to proactive and adaptive management models focused on preserving knowledge, developing competencies, and increasing the resilience of public institutions.

Thus, the methodology and technologies of big data form the basis for the transition to more flexible and sustainable models of intellectual capital management in the public sector of the economy. Their use in conditions of instability or crisis allows not only to increase the current efficiency of enterprises, but also to create the prerequisites for long-term development and strengthening of their competitive positions.

Summary and conclusions.

The above analysis shows that intellectual capital is a key strategic asset of public sector enterprises, in particular in conditions of increased instability and crisis processes. At the same time, established management approaches often ignore the variability of the external environment, which leads to a decrease in the effectiveness of their application. It is big data technologies that allow us to move to an analytically based management model, identify hidden relationships and effectively allocate resources. In other words, it is the application of big data technologies that allows us

to significantly increase the transparency of management processes and the quality of decisions made, ensuring a comprehensive study of human, structural and relational capital.

Big Data opens up the opportunity to identify hidden dependencies and trends, predict needs for competencies, optimize business processes and improve interaction with external partners. Testing the model on conditional data showed that analytical tools are able to identify bottlenecks, identify groups of employees with high potential and form recommendations for adjusting intellectual capital management strategies.

Empirical testing has shown that analytical tools help identify bottlenecks and formulate recommendations for adjusting strategies. At the same time, the results of the analysis may vary depending on the quality of the source data.

The practical value of implementing Big Data is to increase the adaptability of state-owned enterprises, develop their innovative potential and the ability to more effectively perform socially significant functions in conditions of instability. The intellectual capital management model based on Big Data technologies allows not only to systematize and structure data, but also to transform it into a managerial value capable of supporting sustainability and competitiveness.

Further research should be focused on empirical testing of the proposed model in real conditions, developing industry indicators for assessing intellectual capital and studying the economic and social effects of implementing Big Data in the public sector. At the same time, it is advisable to focus on adapting personnel and optimizing internal organizational procedures for the purpose of effective practical use of analytical tools. Individual indicators may vary depending on the level of reliability and completeness of the initial information, and therefore the implementation of the proposed model should provide for a phased verification of the results and their further refinement.

Discussion.

The authors put forward the following debatable thesis: the use of HYBRID Big Data technologies will significantly increase the efficiency of intellectual capital management of competitive public sector enterprises, especially in conditions of instability and crisis.

Analysis of promising practices showed that it is the hybrid integration of machine learning methods, big data analytics and intelligent decision support systems that allows public organizations to respond more flexibly to external and internal challenges, optimize resource allocation processes and strengthen innovation potential. One of the key promising prerequisites is that hybrid approaches (which synergistically combine classical statistical analytics and modern artificial intelligence algorithms [60], [61]) - provide more accurate forecasting of needs and risks associated with intellectual capital. In particular, such technologies allow you to identify hidden patterns in the knowledge and competencies of employees, predict possible skill shortages and form strategies for their prompt replenishment. This is especially true for state organizations, where the efficiency of intellectual capital affects the quality of service provision and strategic sustainability.

However, the implementation of such hybrid Big Data technologies faces a number of practical and organizational barriers. Among them are the limited number of qualified personnel, the high cost of technology implementation, and the need to ensure information security. In addition, the results of the analysis show that the effectiveness of such solutions largely depends on the maturity of the organizational structure and the level of digital literacy of employees. This indicates the need for a comprehensive approach that combines technical, managerial, and educational measures.

Thus, the authors advance the following argumentative thesis: the integration of technical innovations with organizational and social aspects will increase the adaptability of state-owned enterprises and strengthen their competitiveness even in an unstable economic environment.

It is this direction of actual scientific and practical research of the authors that will be revealed in detail in the following publications.

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