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THE ROLE OF INTELLECTUAL TECHNOLOGIES AND TACTICAL MODELING IN ENSURING STATE BORDER SECURITY

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Abstract

This article analyzes the issues of transforming the state border security system in the modern geopolitical context. The possibilities of applying artificial intelligence (AI), autonomous sensor networks, and tactical modeling methods in the operational command and control echelons of border troops are scientifically and theoretically substantiated. Furthermore, the prospects for implementing intellectual platforms in the state border protection system of the Republic of Uzbekistan are examined.

Keywords: State border, national security, artificial intelligence, Big Data, asymmetric threats, cognitive management, unmanned aerial vehicles (UAVs), border monitoring.

Introduction

The first quarter of the 21st century has entered the history of humanity and the system of international relations as an era of radical transformation of the global security architecture and the evolutionary change in the nature of transnational threats. The emergence of hybrid wars, proxy conflicts, and asymmetric risks necessitates a fundamental revision of the national security concept. Within this framework, the notion of the state border is no longer merely a linea

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r-territorial demarcation on maps or a static geographical boundary. In contemporary military-strategic relations, the state border has evolved into a multifunctional dynamic geopolitical system operating in real time, intrinsically linking national sovereignty, economic stability, demographic security, and cyberspace defense.

The state border represents one of the most critical elements ensuring the sovereignty and territorial integrity of every nation. In recent decades, the sharp escalation of global security threats has made border protection increasingly urgent. Threats such as transnational crime, illegal migration, terrorism, and the illicit trafficking of narcotic substances require that state borders be safeguarded not only through physical protection but also through modern technologies, international cooperation, and strategic approaches. This article examines the role and significance of intellectual technologies and tactical modeling in ensuring state border security.

Today, technologically and tactically transformed transnational criminal networks, diversionary-terrorist group activities, drug trafficking, smuggling operations, and illegal migration flows have become highly adaptive in nature. Consequently, the protection and defense of state borders through traditional engineering-technical barriers, stationary checkpoints, and purely physical human resources (border patrols) cannot provide comprehensive resilience and strategic advantage against modern threats. Classical border defense elements exhibit cognitive vulnerability when confronted with contemporary infiltration methods and high-tech threats (Table 1).

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Table 1. Conceptual Comparative Matrix of Border Security Systems

Evaluation Criteria	Traditional Defense System	Intellectual (AI-based) System
Nature of Defense	Static and linear (engineering barriers, barbed wire, fixed observation towers)	Dynamic and multi-echelon (cyberspace defense, virtual borders, deep monitoring)
Data Processing	Fragmented — border patrols manually analyze signaling messages	Fused (Data Fusion) — heterogeneous data streams are integrated in real time using Big Data algorithms
Reaction Speed (OODA Loop)	High cognitive load and decision-making delays due to human factors	Automated millisecond-level response through AI and DSS (Decision Support Systems)
Threat Differentiation	High false alarm rate (weather, animal movements distract patrols)	Neural networks analyze thermal and motion signatures (patterns) of objects with precise filtering
Tactical Resource Management	Static distribution of border patrols based on schedules and plans	Dynamic allocation of forces and assets based on situational threat assessment

As evident from the table, the transition to digital concepts does not imply abandoning physical border guarding but rather synthesizing traditional engineering elements with intelligent control algorithms, thereby multiplying the resilience of defense.

Contemporary border conflicts and asymmetric threats are characterized by extreme dynamism, stochasticity (unpredictability) of event development, and the fracturing of temporal and spatial constraints in tactical operations. The tactical environment changes within seconds, demanding that commanding officers make optimal decisions within milliseconds.

In this highly complex and intense environment, the rapid-operational command bodies of border troops receive an enormous volume of unprocessed, unsystematized data streams (Big Data) from heterogeneous sensors, unmanned aerial vehicles, radar systems, and seismic networks. The human brain's capacity

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to receive and process information becomes cognitively overloaded when confronted with this deluge of data.

Core problem: The abundance of data does not guarantee its effective utilization. Unanalyzed information can paralyze the operational intelligence of command staff.

To address this systemic challenge, ensure the responsiveness of border defense, and optimize the decision-making cycle, the comprehensive digitalization of border infrastructure and the implementation of intelligent systems based on artificial intelligence (AI) algorithms have become an urgent imperative of our time. This research is specifically dedicated to optimizing multi-sensor data fusion and intelligent decision-making mechanisms in border management.

In modern border management, the central mechanism for achieving information superiority is the synthesis of dispersed, multi-format data from all active and passive sensors located across various terrains and echelons of the border area into a unified, coherent Common Operating Picture (COP). In military information technology and cybersecurity doctrines, this complex conceptual process is termed Multi-Sensor Data Fusion.

Border defense units receive gigabytes of information flow in real time from the following asynchronous sources:

- Autonomous and semi-autonomous platforms: Multifunctional aerial (UAVs), ground (UGVs), and underwater unmanned robotic systems;
- Seismic and acoustic networks: Concealed subsurface sensor systems detecting ground vibrations and sound waves;
- ptoelectronic and radar complexes: Infrared (thermal) surveillance cameras, laser rangefinders (LiDAR), and short-range tactical radars;
- Open-source and space-based intelligence (OSINT/GEOINT): Topographic and meteorological updates from low-orbit satellite constellations.

The integration of these diverse assets into a unified network is based on the standards of the US Department of Defense's JADC2 (Joint All-Domain

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Command and Control) concept. The objective is to provide the decision-making center not with raw sensor data but with thoroughly analyzed tactical meaning. The fusion process can be modeled through the cognitive framework of the JDL (Joint Directors of Laboratories) model as follows:

Table 2. DL (Joint Directors of Laboratories) Object Assessment Model

Systemic Level	Functional Name	Technical-Tactical Content and Process Algorithm
Level 0 (Initial Processing)	Data Alignment	Converting asynchronous and fragmented signals from various sensors (e.g., geographic coordinates from radar and pixel streams from optical cameras) into a unified time (UTC) and space (WGS-84) reference frame; filtering noise
Level 1 (Elementary Synthesis)	Object Assessment	Associating unrelated sensor signals (e.g., seismic amplitude from a subsurface sensor and a 37.5°C thermal contour from a thermal camera) into a single object (a border violator); calculating its mass, speed, and vector
Level 2 (Contextual Analysis)	Situation Assessment	Linking the identified physical object's movement route with actual geographic terrain (mountains, desert, river), current weather conditions, and the location architecture of the nearest border posts to produce a comprehensive tactical picture
Level 3 (Strategic Forecasting)	Threat Assessment	Forecasting the object's likely criminal or military intent based on tactical movement; determining the level of potential threat (e.g., ordinary smuggling, covert crossing by an armed group, or risk of diversionary engagement) and generating alerts on the commander's console

This four-stage model demonstrates how AI algorithms can systematize data orders of magnitude faster and more accurately than the human brain. By delegating Level 0 and Level 1 technical operations to machines, command staff

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are empowered to focus exclusively on Level 2 and Level 3 pure tactical and strategic decision-making.

In traditional border security systems, commanders had to receive each individual signal (monitor, radio message, alarm) and manually synthesize the situation in their minds — a process of cognitive synthesis that was extremely demanding and prone to fatigue-induced oversight of critical factors.

Modern AI algorithms — particularly Deep Learning — perform these stochastic filtering operations in fractions of a second. For example, consider a nighttime border incursion: the system compares seismic network detections of vibrations (up to 50 kg mass) with a 38°C thermal signature from an optical camera and automatically determines that this is the movement of a wild animal (e.g., a boar) rather than an armed border violator, whose movement dynamics (step frequency, group coordination, equipment thermal radiation) exhibit distinct patterns.

Consequently, the digital system functions as an automated "gateway," filtering threats without human intervention. This prevents the wasteful expenditure of border troops' resources (rapid response teams, fuel, ammunition) on false alarm signals and enables the concentration of forces solely in areas of genuine threat.

The exponential growth of information flows in border protection and defense systems introduces new challenges related to the human factor. In traditional systems, commanders and duty operators are compelled to independently analyze data from multiple sources: video surveillance cameras, radio communication devices, seismic sensors, motion detectors, thermal observation systems, and patrol groups. This data is presented in fragmented formats. Integrating this information into a unified operational picture, identifying interconnections, and assessing the situation relies entirely on the commander's cognitive capacity.

In military command theory, this process is referred to as ****Cognitive Synthesis****. During this activity, the human brain simultaneously analyzes dozens of information sources, compares them, and arrives at a consolidated conclusion for decision-making. However, human cognitive capabilities are

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finite; under conditions of massive information flow, decision quality may deteriorate. Psychological research indicates that under prolonged duty shifts, high responsibility, and continuous stress, operators experience **Cognitive Overload**. As a result, critical signals may be overlooked, the situation may be misinterpreted, or the decision-making process may slow down.

This challenge is particularly acute during nighttime operations, in areas with complex terrain, or under adverse meteorological conditions, where distinguishing false signals from genuine threats becomes even more difficult. For instance, movements of wild animals in the border zone, wind-induced vibrations, or technical malfunctions generating signals may be misinterpreted by operators as real threats. Such cases trigger excessive alarm signals, leading to inefficient mobilization of rapid response teams and other resources.

The implementation of artificial intelligence technologies allows this problem to be addressed at a qualitatively new level. Modern Deep Learning algorithms can integrate and automatically analyze data from various sensors in real time. Such systems partially assume the cognitive synthesis function performed by the human brain and automate the preliminary data filtering stage.

Consider a nighttime border detection scenario: a seismic sensor detects ground vibrations indicating the movement of an object of a certain mass. Simultaneously, a thermal camera identifies a heat source within a specific temperature range, while an optical surveillance system tracks the object's silhouette and trajectory. The AI system integrates all this data, analyzing interrelationships across the unified system.

Neural networks, pre-trained on millions of images and movement patterns, can identify distinctive characteristics of various objects. For example, the amplitude, speed, and thermal radiation of wild animals differ significantly from human movement patterns. Similarly, armed individuals or groups typically exhibit specific tactical movement signatures: coordinated directional movement, group formation, additional thermal signatures from equipment, etc. The AI analyzes

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precisely these signatures to classify the probable object category and assess the threat level.

From a technological perspective, this process is grounded in the concept of Sensor Fusion. Sensor fusion systems combine data from multiple independent sources into a unified information model, generating more accurate conclusions than any individual sensor could provide. Thus, the system not only detects movement but also evaluates its nature.

One of the most significant advantages of AI is its immunity to fatigue, loss of attention, and ability to simultaneously analyze thousands of parameters. In modern border security systems, AI-based analytical platforms function as a "digital filter" or "intelligent gateway" for human operators. The system automatically screens all incoming signals, forwarding only high-probability threat situations to human attention.

In military command theory, this approach is known as a Decision Support System (DSS). Such systems reduce commanders' cognitive load, enhance situational assessment accuracy, and shorten decision-making time, significantly improving operational command efficiency.

Practically, this yields important outcomes: reduction in false alarm signals; dispatch of rapid response teams exclusively to areas with genuine threats; conservation of fuel, vehicle resources, and personnel; faster response to real threats; and the ability to concentrate forces at vulnerable border points.

From a socio-philosophical perspective, this process reflects the formation of a new functional collaboration model between humans and AI. AI does not replace humans but serves as a technological tool that expands cognitive capabilities and enhances decision-making quality. As a result, the border security system achieves a harmonious integration of human strategic thinking and AI's high-speed analytical capabilities, creating a more effective and resilient command mechanism. This constitutes one of the fundamental principles of the modern "Smart Border" concept.

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Contemporary border security systems are transitioning from traditional physical control to intellectualized, automated, and data-driven approaches. Several advanced technologies play a critical role in this transformation.

Artificial Intelligence and Machine Learning Systems — AI, Big Data analytics, and machine learning systems are being implemented in public safety domains. These technologies are instrumental in proactive threat detection and preventive measures. Specifically, AI systems serve as effective tools for video analytics, suspicious activity detection, and criminogenic situation forecasting. Modern neural networks and deep learning algorithms enable the automation of complex tasks such as facial recognition systems, voice analysis, and processing of social media data.

Automated Border Control Systems — In February 2020, at a working meeting chaired by the President of Uzbekistan Shavkat Mirziyoyev, special attention was devoted to implementing modern automated border control systems and information and communication technologies. These systems enhance border service efficiency, reduce human error, and ensure rapid response.

In modern border security, tactical modeling and decision support systems play a crucial role. These systems enable commanders to conduct in-depth situation analysis, forecast threats, and develop optimal response measures.

Torch-X™ Borders — a comprehensive command and control solution for border security developed by Elbit Systems. Operating on the C4ISR (Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance) architecture, Torch-X Borders integrates various sensors and tactical elements to provide recommendations based on all available data and combat rules during the decision-making process.

Key system capabilities include:

- Sensor data fusion and enrichment — integrating imagery and data from all sensors to reduce operator cognitive load;

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- Automated threat classification and prioritization — threats are automatically classified and optimal interdiction methods recommended;
- Common operational picture — providing a unified situational awareness and operational language for all forces;
- AI and machine learning tools — scalable AI and tactical decision-support algorithm suites.

Tactical Analysis and Contextual Risk Calculation (TACCRA) — an innovative "digital twin" platform and automated risk algorithm developed by the US Pacific Northwest National Laboratory (PNNL). TACCRA analyzes data in real time to provide comprehensive risk assessments.

Key innovations:

- Dynamic risk algorithm — synthesizing historical data, real-time checkpoint data, and AI-generated forecasts;
- Digital twin technology — enabling users to visualize, simulate, and optimize checkpoint configurations;
- Adaptive approach — integrating multi-factor data including detection technology probabilities, resource availability, screening route characteristics, and threat actor behavioral models to propose flexible strategies.

Simulation and modeling technologies are vital for planning and optimizing border security. Researchers are simulating border security systems using mobile wireless sensor network (WSN) technology. Using the CupCarbon simulator, intrusion detection systems are modeled with sensors deployed along the border.

These simulations enable:

- Real-time alerts to troops regarding ongoing border intrusions;
- Remote monitoring and verification of sensor status;
- Guidance to troops during emergencies via Android applications;
- Performance analysis of applications using machine learning techniques.

Modeling also plays an important role in the activities of Uzbekistan's border troops. Among the functions of state border protection authorities is modeling the

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composition, structure, numbers, and deployment of border troops, as well as their equipping with modern weapons, military equipment, and specialized border protection technical means, in coordination with the General Staff of the Armed Forces of the Republic of Uzbekistan.

International cooperation and experience exchange constitute a significant factor in ensuring state border security. International practice demonstrates that effective border security systems extend beyond the internal resources of a single state. Various countries enhance border protection effectiveness by learning from each other's experiences, implementing modern technologies, and maintaining close cooperation with neighboring states.

Research shows that transnational networks and coordinated actions with neighboring states significantly enhance border security. Through biometric systems, AI, and automated monitoring, border security can be substantially strengthened.

Furthermore, deep analysis and forecasting of situational development characteristics and anticipated scenarios in potential combat zones constitute essential factors in developing border security strategy. Intelligent systems and modeling technologies enable commanders to comprehensively assess situations and make optimal strategic decisions.

In conclusion, intellectual technologies and tactical modeling have become integral components of the modern state border security system. AI, machine learning, Big Data analytics, UAVs, and advanced sensor systems are significantly enhancing border control effectiveness. Comprehensive management systems such as Torch-X Borders and digital twin platforms like TACCRA enable accelerated decision-making, proactive threat forecasting, and optimal resource allocation. As demonstrated by Uzbekistan's example, significant steps are being taken to strengthen border security through the installation of video surveillance systems, the establishment of special units equipped with Bayraktar drones, and the implementation of automated control

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systems. Future development of intelligent technologies and enhanced international cooperation will continue to improve the effectiveness of state border security systems. However, particular attention must be directed to ensuring information security, enhancing personnel qualifications, and developing technological infrastructure.

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