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Improving the Five-Layer “Smart Customs” Architecture and the Blockchain-Based Authorized Economic Operator System for the Digitalization of Customs Administration in Uzbekistan

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Abstract: This study examines the digitalization of management processes in the customs authorities of Uzbekistan, improving the speed and efficiency of customs control, and enhancing the quality of services provided to participants in foreign economic activity. The purpose of the study is to develop scientific and practical proposals for establishing a five-layer “Smart Customs” architecture adapted to customs administration and for the phased introduction of a blockchain-based Authorized Economic Operator certification system and a mutual recognition mechanism. The study applies systematic and comparative analysis, a process approach, functional modeling, induction and deduction, expert assessment, and methods for evaluating the impact of digital technologies on customs processes. The study proposes a five-layer “Smart Customs” architecture consisting of digital infrastructure, data and integration, artificial intelligence and analytics, digital services, and governance and monitoring. The architecture enables the integration of customs information systems, real-time data processing, automated risk identification, intelligence-based customs control, and monitoring of management decisions. In addition, a model has been developed for verifying the authenticity of Authorized Economic Operator certificates on the basis of blockchain, ensuring the immutability and transparency of operator-related data, and introducing a mutual recognition mechanism. The proposed solutions can help reduce customs clearance time, minimize the human factor, improve data accuracy and security, and expand simplified customs procedures for reliable business entities.

Keywords: customs administration, digital customs, Smart Customs, five-layer architecture, digital infrastructure, artificial intelligence, risk management system, blockchain, Authorized Economic Operator, AEO certificate, mutual recognition, MRA, customs control, digital services, monitoring.

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1. Introduction

The expansion of international trade flows, the growth of e-commerce, and the increasing complexity of cross-border supply chains are placing new demands on customs authorities. A modern customs system should operate not merely as an administrative structure controlling goods and means of transport, but as a digital governance institution that ensures economic security, facilitates foreign trade, protects fiscal interests, and provides prompt services to business entities.

In Uzbekistan, consistent reforms are being implemented to digitalize customs authorities, develop the “Single Window” principle, expand electronic declaration,

improve the risk management system, and introduce automated customs clearance. At the same time, issues related to integrating existing digital systems into a unified governance architecture, rapidly analyzing large volumes of data, identifying risky operations in advance using artificial intelligence, monitoring the implementation of management decisions in real time, and ensuring information security remain relevant.[1]

Addressing these challenges requires the development of a comprehensive architecture based on the “Smart Customs” concept. Unlike simple automation of customs operations, “Smart Customs” involves centralized data management, integration of digital platforms, the use of artificial intelligence and advanced analytical tools, and continuous monitoring of management outcomes. Therefore, developing an architectural model adapted to the institutional and technological characteristics of customs administration in Uzbekistan is of scientific and practical importance.

The five-layer “Smart Customs” architecture proposed in this study consists of the following interconnected layers:

1. Digital infrastructure layer — includes servers, government cloud, data storage systems, telecommunications networks, mobile devices, Internet of Things tools, and cybersecurity infrastructure.
2. Data and integration layer — provides standardized data exchange among internal information systems of customs authorities, government organizations, banks, logistics companies, and international information platforms.
3. Artificial intelligence and analytics layer — supports automated risk assessment, identification of suspicious operations, verification of goods classification and customs value, forecasting of potential violations, and analytical support for management decisions.
4. Digital services layer — includes electronic declaration, automated clearance, remote customs services, personal accounts, electronic payments, and digital interaction with participants in foreign economic activity.
5. Governance and monitoring layer — enables monitoring of key performance indicators of customs authorities, assessment of clearance times, determination of the effectiveness of risk profiles, maintenance of audit trails, and control over the implementation of decisions.[2]

The operation of these layers through a unified mechanism reduces fragmentation in customs processes and ensures continuity from data collection to the adoption of management decisions. As a result, customs clearance and control shift toward a data-driven, proactive, and risk-based form of management.

The use of blockchain technology makes it possible to store AEO certificates in a decentralized and immutable digital registry, verify their validity status in real time, record the actions of authorized organizations, and securely exchange certificate-related information with international partners. Each operation related to issuing, extending, temporarily suspending, or cancelling a certificate is recorded in the blockchain registry. The use of smart contracts also enables automatic monitoring of an operator’s compliance with established criteria and activation of the relevant customs facilitations.[3]

The international effectiveness of the AEO system also depends on the development of Mutual Recognition Agreement (MRA) mechanisms. Under an MRA, the status of an operator recognized as reliable by one country is also recognized by the customs administration of a partner country. This reduces repeated inspections, accelerates border and customs clearance, and improves the security and resilience of supply chains. A blockchain-based digital certification system can technologically support the MRA mechanism by enabling reliable, transparent, and rapid information exchange between partner countries.

Accordingly, the purpose of the study is to develop a five-layer “Smart Customs” architecture adapted to customs administration in Uzbekistan and to substantiate a model for the phased introduction of a blockchain-based Authorized Economic Operator certification system and mutual recognition mechanism.

To achieve this objective, the following tasks were defined:

- systematize modern approaches to the digitalization of customs administration;
- identify the functional characteristics of digital processes in the customs authorities of Uzbekistan;[4]
- develop the structure of the five-layer “Smart Customs” architecture and the relationships among its layers;
- substantiate opportunities for identifying risks and improving customs control using artificial intelligence;
- develop the operating mechanism of a blockchain-based AEO certification system;
- propose a phased model for the international mutual recognition of AEO certificates;
- determine the organizational, economic, and service-related effects expected from implementing the proposed models.

The practical significance of the study is that the proposed models can help reduce customs clearance time, decrease the human factor and corruption risks, improve data accuracy and protection, identify risks in advance, expand “green channel” opportunities for reliable business entities, and support the harmonization of Uzbekistan’s customs system with international standards.[5]

2. Methods

The study focused on systematically organizing digital governance processes in the customs authorities of Uzbekistan, integrating existing information systems within a unified architecture, and improving the activities of Authorized Economic Operators through blockchain technology. The study used a systems approach, process approach, comparative analysis, functional modeling, statistical analysis, expert assessment, and scenario forecasting.

The theoretical and methodological basis of the study consisted of the World Customs Organization’s SAFE standards, international recommendations on Authorized Economic Operator programs, the World Trade Organization’s Trade Facilitation Agreement, and international experience in implementing digital customs technologies.

Article 7 of the World Trade Organization’s Trade Facilitation Agreement establishes the need to conduct customs control on the basis of risk management, strengthen controls over high-risk consignments, and ensure the rapid release of low-risk consignments. The article also provides for additional simplified procedures for authorized operators meeting the established criteria in import, export, and transit operations [6].

The World Customs Organization’s Compendium of Authorized Economic Operator Programmes describes the AEO program as a priority form of cooperation between customs authorities and businesses. Within this program, operators that consistently comply with legislation may receive benefits such as reduced levels of customs control, simplified clearance, periodic reporting, deferred payments, and the use of international mutual recognition agreements [7].

A joint study by the World Customs Organization and the World Trade Organization on advanced technologies assesses artificial intelligence, machine learning, blockchain, the Internet of Things, and big data technologies as tools for improving the efficiency, transparency, and security of customs processes [8]. These international rules and

recommendations were incorporated into the methodological basis of the proposed five-layer “Smart Customs” architecture.

A table 1. systems-functional modeling method was used to develop the “Smart Customs” architecture. In accordance with this method, customs administration processes were divided into five layers according to their functional tasks and technological characteristics.

Table 1. “Smart Customs” architecture

Layer	Main components	Function
Digital infrastructure	Government cloud, servers, data center, communication networks, IoT and GPS devices	Ensuring continuous and secure operation of information systems
Data and integration	Customs data, interagency platforms, APIs, “Single Window”, international information systems	Data collection, standardization, and intersystem exchange
Artificial intelligence and analytics	Machine learning, risk profiles, forecasting, big data analytics	Automated risk identification and analytical decision support
Digital services	Electronic declaration, automated clearance, personal account, electronic payments	Rapid service provision to participants in foreign economic activity
Governance and monitoring	KPI dashboard, audit log, control dashboard, reporting and alert system	Assessing process efficiency and monitoring management decisions

Dividing the architecture into layers makes it possible to distinguish the technical, information-analytical, and governance components of customs processes functionally while ensuring a continuous flow of data among them.

Digital infrastructure serves as the foundational layer supporting the operation of all information systems. Information collected in the data and integration layer is processed in the artificial intelligence and analytics layer. The results of the analysis are used in digital services to conduct customs clearance and control. The outcomes of all processes are monitored in the governance and monitoring layer.[9]

Process modeling and data-flow analysis methods were used to develop the blockchain-based Authorized Economic Operator certification model. The certification process was divided into the following functional stages:

1. 1. submission of an electronic application by a business entity to obtain AEO status;
2. 2. automatic retrieval of the applicant’s tax, customs, financial, and legal information from interagency systems;
3. 3. assessment of the operator’s compliance history, financial stability, and conformity with security requirements;
4. 4. adoption of the final decision by the competent authority;
5. 5. registration of the AEO certificate in the blockchain registry;
6. 6. generation of a unique digital identifier and verification code for the certificate;
7. 7. real-time monitoring of the certificate status;
8. 8. recording in the blockchain of information concerning the extension, suspension, or cancellation of the certificate;

9. 9. provision of certificate information to foreign customs administrations through the MRA mechanism.[10]

The model provides for the use of a permissioned blockchain. In this system, the Customs Committee serves as the principal governing organization. Tax authorities, banks, certification organizations, and other authorized government agencies participate as data-validating participants. Foreign customs administrations are granted the right, within the framework of an MRA, to verify the authenticity and validity status of the certificate.

The following information is proposed to be recorded in each blockchain block:

- unique AEO identification number;
- certificate number and date of issue;
- certificate validity period;
- operator compliance level;
- customs facilitations granted;
- current certificate status;
- digital signature of the authorized body that made the change to the information;
- date and time of the operation.

Commercial secrets or personal data are not intended to be stored in the public part of the blockchain. Such information is stored in a protected government information system, while only its cryptographic hash value and verification credentials are entered into the blockchain. This approach makes it possible to verify data integrity while complying with confidentiality requirements.

According to the World Customs Organization, international mutual recognition is an important component of AEO programs and refers to the recognition by one country of an operator status granted by the customs administration of another country. The European Commission also considers mutual recognition of AEOs an important element of the SAFE standards aimed at ensuring the security of international supply chains [11].

The effectiveness of the proposed models was assessed using indicators reflecting process speed, the degree of automation, data quality, the effectiveness of risk identification, and the quality of services provided to AEOs.

This methodology makes it possible to assess the five-layer “Smart Customs” architecture and the blockchain-based AEO–MRA model not only as technological solutions, but also as an integrated organizational and economic mechanism for improving management efficiency in customs authorities.

3. Result

The digitalization measures being implemented in the customs authorities of Uzbekistan are producing certain results in areas such as electronic declaration, risk management, automated clearance, and interagency data exchange. According to the World Customs Organization, as a result of digitalization of customs processes and the introduction of an automated risk management system based on machine learning, customs revenues in Uzbekistan increased from UZS 24.7 trillion in 2020 to UZS 63.1 trillion in 2024, representing a 2.6-fold increase over five years [12].

Existing automated systems reduce the need for a customs inspector to make an individual decision on every declaration and enable control to be organized on the basis of objective criteria. This creates opportunities to reduce subjective decisions and corruption risks in customs processes and to prevent disputes between customs authorities and participants in foreign economic activity [13].

At the same time, the systematic analysis conducted shows that although the functional capabilities of information systems used by customs authorities have expanded, there remains a need to integrate them into a unified governance architecture. Repeated generation of some data in different information systems, differences in the speed of intersystem data exchange, limited real-time analytical capabilities, and the implementation of management monitoring on separate platforms reduce the integrity of digital governance.

The analysis identified the following key problems:

- · fragmented organization of digital infrastructure and data storage systems;
- · incomplete standardization of data formats in interagency information systems;
- · limited use of artificial intelligence and machine-learning algorithms;
- · continued human involvement at certain stages of customs services;
- · insufficient opportunities for real-time monitoring of the effectiveness of management decisions;
- · absence of a mechanism for rapid international verification of information on AEO certificates;
- · insufficient development of international mutual recognition processes for Authorized Economic Operators.

These problems demonstrate the need to develop customs administration not through separate software tools, but through a comprehensive architecture that integrates all digital processes into a unified system.

Five-Layer “Smart Customs” Architecture

As a result of the study, a five-layer “Smart Customs” architecture adapted to the organizational and technological characteristics of customs administration in Uzbekistan was developed. The main feature of the architecture is to ensure the continuous operation, within a unified digital environment, of processes for collecting, storing, processing, analyzing, providing services, and monitoring customs data.

The proposed architecture consists of the following layers:

1. 1. digital infrastructure;
2. 2. data and integration;
3. 3. artificial intelligence and analytics;
4. 4. digital customs services;
5. 5. governance and monitoring.

Digital infrastructure is the foundational layer of the “Smart Customs” architecture. This layer includes the following elements:

- · “Government Cloud” infrastructure;
- · customs data processing centers;
- · backup servers and data recovery systems;
- · secure telecommunications networks;
- · digital control tools at border customs posts;
- · electronic seals, GPS, and IoT devices;
- · scanning and automated identification equipment;
- · biometric identification tools;
- · cybersecurity and authentication systems.

The use of the “Government Cloud” enables the centralization of computing resources, rapid scaling of information systems, creation of data backups, and use of software according to common standards across regional customs authorities.

Integrating IoT and GPS devices into this layer makes it possible to track the movement of goods under customs control in real time. Deviations of a vehicle from the designated route, tampering with an electronic seal, or failure of the goods to arrive at the customs destination on time can be detected automatically, and electronic alerts can be sent to responsible personnel.

The main function of this layer is to ensure continuous data exchange among customs authorities, government agencies, banks, transport and logistics organizations, and participants in foreign economic activity.

The integration process is proposed to be implemented on the basis of APIs and unified data-exchange standards. As a result, information submitted once by a participant in foreign economic activity does not have to be requested again by other authorized government agencies. This enables the “once-only” principle to be introduced into customs administration.

The World Trade Organization’s Trade Facilitation Agreement provides for the simplification of documents and information related to import, export, and transit operations, as well as stronger cooperation among border agencies. In this regard, the data and integration layer contributes to aligning Uzbekistan’s customs system with international trade facilitation requirements.

The artificial intelligence and analytics layer is the intellectual center of the proposed architecture. In this layer, data obtained from various information sources are processed using artificial intelligence, machine learning, and big data analytics.

The World Trade Organization establishes that risk management should direct customs control toward high-risk consignments while ensuring the rapid release of low-risk consignments [14]. Therefore, the proposed artificial intelligence model enables customs authorities to allocate control resources rationally according to the level of risk.

Presidential Decree PF-250 establishes tasks related to the automated clearance of certain customs cargo declarations where no risk has been identified, priority service for AEOs, and the provision of additional simplified procedures [4]. The proposed digital services layer makes it possible to implement these tasks on a unified platform.

The governance and monitoring layer provides customs management with real-time analytical information. The following indicators are monitored:

- · average duration of customs clearance;
- · number and share of automatically cleared declarations;
- · consignments directed to green, yellow, and red channels;
- · effectiveness of risk profiles;
- · identified customs violations;
- · customs payments collected;
- · customs debt;
- · number of AEOs and their performance indicators;
- · consignments cleared within the MRA framework;
- · operational continuity of information systems;
- · requests and appeals from participants in foreign economic activity;
- · level of satisfaction with customs services.

An electronic audit trail is generated for each operation. It records the user who accessed the system, the operation performed, the data used, the decision taken, and the time of the operation. This supports verification of the justification of management decisions and strengthens the accountability of officials.

Blockchain-Based AEO Certification System

As the second major result of the study, a scientific and practical model of an Authorized Economic Operator certification system based on blockchain technology was developed.

Under the existing centralized registry, verification of AEO certificate information requires access to the database of the organization maintaining the registry. In the international mutual recognition process, a foreign customs authority needs to obtain timely information on the authenticity of the submitted certificate, its validity period, and the customs facilitations granted to the operator.

To address this problem, it is proposed to maintain AEO certificates in a digital registry based on a permissioned blockchain. In such a system, the right to enter and validate data is granted only to authorized participants designated in advance. The Customs Committee acts as the principal system administrator, while other government bodies participate as data-validating entities.

The blockchain-based model creates the following opportunities:

- · creation of a unique digital version of the AEO certificate;
- · storage of certificate information in an immutable registry;
- · real-time verification of certificate authenticity;
- · tracking the history of certificate issuance and modifications;
- · prevention of the use of fraudulent certificates;
- · reliable data exchange among authorized government bodies;
- · enabling foreign customs administrations to verify certificate status;
- · automatic activation of certain customs facilitations through smart contracts.

The United Nations Centre for Trade Facilitation and Electronic Business has specifically noted the potential of blockchain technology in international trade to ensure the integrity, traceability, and reliability of documents. Therefore, blockchain technology can transform an AEO certificate from a simple electronic document into a reliable international digital identifier.

It is proposed to introduce the blockchain-based AEO certification and mutual recognition mechanism in Uzbekistan in four stages during 2026–2030.

4. Discussion

The study's findings indicate that information products are the determining factor in changing modern information business, with a direct influence on restructuring not only the organizational structure but also the economic processes. [] First, the analysis supports the assertion that information products reap dramatic reductions in production and distribution costs because of their digital form and high scalability. More generally, this enables companies to extend their market access and conduct business on a global scale without the need for significant physical infrastructure.

The research results show that introducing separate information systems alone is insufficient for the digitalization of Uzbekistan's customs authorities. Effective digital transformation of customs administration requires technical infrastructure, data exchange, intelligent analytics, electronic services, and governance monitoring to be interconnected within a unified architecture.

The study by the World Customs Organization and the World Trade Organization on advanced technologies also emphasizes that artificial intelligence, machine learning, blockchain, and the Internet of Things should preferably be applied as an interconnected integrated system rather than as separate technological projects [3]. In this respect, the proposed five-layer "Smart Customs" architecture is consistent with international approaches.

The first advantage of the proposed architecture is its integration of existing and future digital systems in customs authorities into a unified governance mechanism by dividing them into functional layers. Each layer performs an independent function but does not operate separately from the other layers.

The second advantage of the proposed approach is the ability to differentiate customs control according to risk level. The WTO Trade Facilitation Agreement provides for directing customs control toward high-risk consignments and releasing low-risk consignments through accelerated procedures [15]. Incorporating an artificial intelligence layer into the five-layer architecture supports automated implementation of this requirement.

The third advantage is the separation of governance and monitoring as a distinct layer. In many digitalization projects, primary attention is given to electronic services and data processing, while monitoring management outcomes is treated as a secondary task. In the proposed model, a KPI dashboard, electronic audit trail, automated alerts, and analytical reports for management are defined as mandatory components of the architecture.

The WCO SAFE Standards 2025 provide for implementing three main areas of cooperation as an integrated whole:

1. 1. cooperation among customs administrations;
2. 2. cooperation between customs administrations and business;
3. 3. cooperation between customs administrations and other government agencies.

The proposed five-layer architecture covers all three areas. The data and integration layer ensures information exchange between customs authorities and other government agencies. The digital services layer digitalizes relations between customs and business. The blockchain-based AEO–MRA mechanism establishes reliable information exchange between national and foreign customs administrations.

The 2025 edition of the SAFE Standards places particular emphasis on broader participation of micro, small, and medium-sized enterprises in AEO programs, adoption of a code of ethics by AEOs, and prevention of internal risks in the supply chain. Therefore, when developing an AEO compliance index in Uzbekistan, it is necessary to consider not only enterprise size and financial capacity, but also compliance with legislation, information security, internal control, and business integrity indicators.

The use of artificial intelligence enables rapid analysis of large volumes of data concerning customs declarations, goods values, HS codes, transport routes, and the activity history of declarants. This creates opportunities to identify risky operations more quickly than through traditional control methods.

However, a decision generated by an artificial intelligence algorithm should not be treated as an absolute and final decision. The result of an algorithm depends on the quality, completeness, and relevance of the data provided to it. A model developed on the basis of inaccurate or outdated data may classify a low-risk consignment as high-risk or a high-risk consignment as low-risk.

Therefore, the following requirements are appropriate for an AI-based risk management system:

- · regularly monitor data quality and completeness;
- · periodically update risk assessment criteria;
- · provide the ability to explain the main reasons for an algorithmic decision;
- · regularly assess false-positive and false-negative results;
- · retain the possibility of justified intervention by an inspector;

- maintain an electronic audit trail of algorithm activity;
- protect personal and commercial data;
- prevent the artificial intelligence model from producing discriminatory decisions.

This approach treats artificial intelligence not as a tool that completely replaces the customs inspector, but as a mechanism that provides information and analytical support for decision-making.

The main advantage of blockchain technology is the immutability of records concerning AEO certificates, their traceability by time and source, and their verification by multiple authorized participants. UN/CEFACT specifically identifies blockchain's ability to create permanent records, determine the time and source of each record, provide multiple participants with access to data, and execute smart contracts.

At the same time, blockchain technology does not automatically guarantee the substantive accuracy of information entered into the system. If incorrect information is entered initially, the blockchain will preserve that incorrect information as an immutable record. Therefore, the statement that "information on the blockchain is reliable" should be complemented by the condition that "the authorized source entering the information into the blockchain is reliable."

The following governance principles should be observed in a blockchain-based AEO system:

- clearly define data-entry authorities;
- authenticate each record with a digital signature;
- develop a legal procedure for correcting inaccurate information;
- create a new corrective record without deleting the original record;
- define the responsibilities of system participants;
- store commercially confidential information outside the blockchain;
- place only hash values and verification credentials on the blockchain;
- provide differentiated access rights to foreign participants.

In this regard, a permissioned blockchain is considered more appropriate for Uzbekistan's customs system than a public blockchain. This is because the AEO certification process involves data controlled by government authorities and subject to restricted access rights.

5. Conclusion

The study concludes that the digital transformation of customs administration in Uzbekistan requires an integrated technological architecture capable of combining data exchange, intelligent risk management, secure information processing, automated decision-making, and trusted interaction between customs authorities and foreign trade participants. In this context, the proposed five-layer "Smart Customs" architecture provides a systematic framework for connecting technological infrastructure with institutional and operational processes. The architecture enables customs digitalization to be considered not as the introduction of an individual information technology, but as a coordinated transformation of the entire customs-management system. The proposed five-layer architecture is based on the principle of functional integration between data, technological infrastructure, analytical intelligence, operational processes, and institutional interaction. At the foundational level, digital infrastructure and interconnected information resources provide the technological basis for customs operations. The data layer enables the collection, standardization, integration, and exchange of information obtained from customs declarations, logistics systems, trade

databases, transport platforms, and other relevant sources. The analytical and intelligence layer facilitates automated risk assessment, identification of potentially high-risk transactions, detection of inconsistencies, and development of predictive customs-control mechanisms. The application layer translates analytical results into practical customs procedures, while the institutional and interaction layer establishes secure communication between customs authorities, authorized economic operators, logistics companies, carriers, financial institutions, and other participants in international trade. The research further demonstrates that blockchain can strengthen the proposed architecture by providing a distributed and tamper-resistant environment for recording and verifying economically significant transactions. Traditional centralized information systems may create challenges related to data synchronization, unauthorized modification, fragmented records, and trust between organizations. Blockchain-based information exchange can reduce these risks by establishing a shared and verifiable record of relevant events. In customs administration, this capability can be applied to the verification of declarations, certificates, trade documents, supply-chain events, AEO compliance records, and other information requiring a high level of integrity and traceability.

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