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Digitisation of the processes of customs clearance of goods with the calculation of the mathematical model of fuzzy logic

Heorhii Prokudin*
Doctor of Technical Sciences, Professor
National Transport University
01010, 1 M. Omelyanovych-Pavlenko Str., Kyiv, Ukraine
https://orcid.org/0000-0001-9701-8511

Oleksii Chupailenko
PhD in Technical Sciences, Associate Professor
National Transport University
01010, 1 M. Omelyanovych-Pavlenko Str., Kyiv, Ukraine
https://orcid.org/0000-0002-4837-0727

Yurii Kolesnyk
Postgraduate Student
National Transport University
01010, 1 M. Omelyanovych-Pavlenko Str., Kyiv, Ukraine
https://orcid.org/0000-0002-8079-9961

Arkadii Kozlov
Associate Professor
National Transport University
01010, 1 M. Omelyanovych-Pavlenko Str., Kyiv, Ukraine
https://orcid.org/0000-0002-0170-7222

Dmytro Svirin
Associate Professor
National Transport University
01010, 1 M. Omelyanovych-Pavlenko Str., Kyiv, Ukraine
https://orcid.org/0000-0001-5860-4446

Mykhailo Holovatiuk
Assistant
National Transport University
01010, 1 M. Omelyanovych-Pavlenko Str., Kyiv, Ukraine
https://orcid.org/0009-0005-0331-0105

Abstract. The relevance of this study arises from the growing reliance on automated customs clearance systems that generate recommendations, alerts, and justifications in order to reduce processing time. However, the effectiveness of such systems depends on a scientifically grounded methodology for determining the optimal frequency of risk profile reviews and for improving quantitative risk assessment. The purpose of the study was to develop a mathematical model for verifying the accuracy of customs clearance using the apparatus of fuzzy logic in international cargo transportation. The research methods included the development of mathematical models and algorithms for their implementation. In particular, the mathematical apparatus of fuzzy logic was applied to determine the correctness of customs clearance of

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*Corresponding author

goods. It was shown that the identification of customs clearance objects using fuzzy logic apparatus allows to automate the processing of information that is given in the customs declaration, the consumer documents and technical documentation. And which is submitted to the customs authorities with the control of the legalness of the classification of goods using the apparatus of fuzzy logic. Recommendations were developed for the use of the fuzzy logic apparatus in an automated expert system to determine the correctness of customs clearance of goods. This system was intended to enhance control over the correctness of goods classification during customs clearance and to prevent evasion by participants of foreign economic activity from paying taxes in full and from complying with non-tariff regulation measures through violations of declaration rules for goods crossing the customs border of Ukraine. It was also aimed at reducing the time of customs clearance, providing direct solutions to complex and contradictory classification problems arising during clearance, and avoiding errors in the classification of goods

Keywords: information automation; risk management; non-tariff regulation; logistics operators; transport monitoring

Introduction

Risk management is a fundamental principle of modern customs control methods, as it enables the optimisation of costs associated with customs supervision. This principle protects the majority of foreign trade operations from excessive bureaucratic control. It is appropriate to consider the customs risk management system as a set of instruments and management methods based on the principle of selectivity. Such a system reduces the number of customs control forms applied, while ensuring that the chosen measures remain sufficient for compliance with customs legislation. Under current conditions, there is a clear need to establish a customs administration system in Ukraine that is stable, prevents violations of national customs law, increases the collection of customs duties and taxes, and enhances the competitiveness of Ukrainian production. Procedures related to risk management are concentrated customs control in processes. where the highest risk is the registration of customs declarations, which are registered for all goods. In response to the evolving geopolitical environment, Ukraine's customs policy is undergoing significant transformation, accompanied by a documented increase in violations related to the registration of customs declarations for goods and vehicles, which underscores the need for strengthened control mechanisms and improved regulatory oversight (In 2024, customs authorities…, 2025). Therefore, the development of a methodology for maintaining the optimal frequency of review of this risk is relevant. One of the forms of customs control is, first of all, verification of the authenticity of customs declarations.

Systems designed to support decision-making processes, in particular advisory and expert systems, are gaining particular relevance. The name of these systems fully corresponds to their purpose: at the user's request, they "issue" recommendations in a situation that arises during the analysis of objects. The system should issue recommendations at the level of an experienced person, an authority in his field. An expert system is not intended to replace a person who makes decisions, although in extreme cases such a replacement is possible. The use of expert systems and adequate methods of object identification for the needs of customs clearance of goods and customs control is an important and priority area of development of the State Customs Service. L.M. Ivashova & L.I. Kyda (2020) analysed the current state of digital transformation within the Ukrainian customs system, emphasising key technological innovations that contribute to procedural simplification. The author highlighted major challenges and outlines prospects for improving customs administration through modern digital tools and information systems. The study by I. Berestov *et al.* (2022) examined the digitalisation of customs control and cargo-clearance processes in railway transport. The researchers evaluated the impact of digital tools on accelerating clearance procedures and enhancing the efficiency of cargo-flow monitoring. In turn, R. Lemeha (2020) investigated automation and informatisation as priority directions for improving the administration of customs regimes in Ukraine. The publication discussed existing regulatory gaps and proposes digital solutions aimed at strengthening transparency, control, and service quality in customs processes. Similarly, V. Lebid *et al.* (2020) evaluated the efficiency of simplifying customs formalities through digitalisation initiatives. The study provided empirical evidence demonstrating how digital services reduce processing time, minimise administrative barriers, and support overall trade facilitation. A more advanced methodological perspective is presented by N. Luo *et al.* (2023), who offered a comprehensive overview of customs risk-management methods, with particular emphasis on fuzzy-logic and neural-network-based models for assessing risks faced by import-export enterprises. Building on this direction, Z. Dong & M. Tian (2025) proposed a fuzzy-logic-based model for assessing risks in cross-border e-commerce logistics supply chains. The findings showed that fuzzy inference systems can more reliably evaluate dynamic and imprecise data compared to traditional deterministic models. In a related study, C. Zheng *et al.* (2025) developed a data-driven model for optimising customs-clearance strategies for emergency supplies using machine-learning and clustering techniques. Their results highlighted how digital analytics significantly reduce clearance time during crisis situations. Further exploring the technological evolution of customs systems, S. Vijayakumar (2025) investigated technology-centric and data-driven transformations in customs risk management. The author outlined how digital ecosystems, automated control algorithms, and AI-based tools enhance supply-chain security in global trade.

The literature review confirmed that, in the practice of customs clearance, a number of systemic problems persist due to the absence of an effective mechanism for determining the physical, chemical, and other characteristics of goods crossing the customs border of Ukraine. The classification process is complicated by the large volume of input information, inaccuracies in primary data, limited decision-making timeframes, the extensive number of explanatory letters issued by the State Customs Service (SCSU), and an insufficient level of specialised knowledge in certain fields. This highlights the need to improve approaches to goods classification, particularly through the automation of relevant procedures, which would contribute to increasing the accuracy and efficiency of customs control. The aim of the work was to design a model for the digitalisation of customs clearance processes using fuzzy logic in international freight transportation.

Materials and Methods

The object of this study was the processes of customs clearance of declarations in the context of international carriage of goods. The subject of the work was the mathematical model of control of the correctness of filling out customs declarations with the apparatus of fuzzy logic. The method of identification of objects of customs control is aimed at implementing a single algorithm for automated processing of information contained in customs documents (cargo customs declaration; accompanying documents; technical documentation at the level of customs authorities with control over the correctness of the classification of goods; with the issuance of various recommendations, warnings; and also in substantiating the established position for the regular personnel of customs authorities who carry out customs control and customs clearance of goods). Within the framework of the study, the regulatory and legal basis of customs regulation was analysed, in particular the provisions of the Law of Ukraine No. 2697-IX (2023), which defines the structure and content of the Ukrainian Classification of Goods for Foreign Economic Activity (UKTZED). An approach based on the application of fuzzy logic was selected, as it makes it possible to take into account not only precise quantitative data but also qualitative expert assessments. The practice of human decision-making was analysed, since individuals often operate with vague concepts such as “high”, “low”, “near”, “far”, “fast”, and “slow”, which reflect the subjective perception of information. The choice of fuzzy logic was justified by its ability to formalise and process such qualitative expert knowledge while preserving important information derived from professional experience, and at the same time ensuring objective data processing within expert systems. The use of this approach enables the effective handling of qualitative and incomplete data under conditions of limited time. Goods were considered as a set of fuzzy statements with corresponding degrees of truth within the interval [0; 1], which made it possible to represent expert knowledge in a formalised manner. On the basis of fuzzy logic operations (conjunction, disjunction, and negation), mathematical models and algorithms were developed to determine the assignment of customs control objects to specific UKTZED subcategories. The practical implementation of the methodology was demonstrated through examples of classifying motor vehicles under heading 8703 and motor gasolines under heading 2710, which confirmed the potential to increase the accuracy, objectivity, and efficiency of customs control by automating classification procedures.

Results

Significant challenges exist in the classification and identification of goods, as there is currently no effective and reliable system for determining their physical, chemical, and other properties when crossing the customs border of Ukraine. Goods are classified according to the UKTZED, established by the Law of Ukraine No. 2697-IX (2023). The main problems of correct classification: a large volume of input information; inaccuracy (inaccuracy) of primary data; short deadlines for making a decision on assigning a commodity code; a large number of information letters from the SCSU; lack of a sufficient level of knowledge in some areas, including specific knowledge (chemical industry, light industry, mechanical engineering, electronics, agriculture, etc.) (Chupailenko *et al.*, 2023). Automation of the process of classification of goods would solve a number of issues that arise in the process of customs clearance. Fuzzy logic enables the processing of information that contains expert knowledge and experience, which are difficult to formalise into precise numerical values. As a result, expert systems based on fuzzy logic can effectively integrate quantitative and qualitative data, assess information objectively, and make decisions under time constraints, making them particularly relevant for modern complex systems (Mishchenko *et al.*, 2020; Kostiana *et al.*, 2021). The mathematical apparatus of fuzzy logic is at once the most adequate, it allows to maximally shorten the transition from a verbal, verbal, qualitative description of an object, which characterises human thinking, to numerical quantitative assessments of its state. This makes it possible to formulate on this basis simple and effective algorithms to model human thoughts and human ability to perform tasks. The possibility of identifying objects of customs control for commodity item 8703, according to the Ukrainian Classification of Economic Activities (object class “passenger car”), can be considered using the mathematical apparatus of fuzzy logic (Table 1).

Table 1. Characteristics determining for classification of product

$\tilde{a}_1$	"Cars and other motor vehicles"
$\tilde{a}_{12}$	"Motor vehicles equipped for temporary human consumption"
$\tilde{a}_{13}$	"Other transport means"
$\tilde{a}_{21}$	"Spark-ignition internal combustion engine with a cylinder capacity exceeding 2,200 cm^3 but not exceeding 3,000 cm^3"
$\tilde{a}_{22}$	"Compression-ignition internal combustion engine (diesel or semi-diesel)"
$\tilde{a}_3$	"Another engine"
$\tilde{a}_4$	"New"

Source: developed by the authors

Table 1 presented a structured set of classification characteristics used to identify motor vehicles within the UKTZED and summarised key technical and functional parameters that determine the correct assignment of a product to a specific tariff heading when performing customs clearance procedures. The provided characteristics encompass several essential classification criteria. These include the general category of the vehicle, such as passenger cars and other motor vehicles, as well as its functional purpose, for example, vehicles equipped for temporary human use. The type of engine, whether spark-ignition, compression-ignition, or other types, is also considered, along with the engine cylinder capacity, which serves as a critical parameter for tariff differentiation. Additionally, the condition of the vehicle, particularly whether it is new, is taken into account. Table 1 demonstrated a clear hierarchical structure, progressing from broad product categories to more detailed technical specifications that influence tariff classification. Such structuring is fundamental for ensuring accurate product identification during customs control, the correct application of customs duties and excise tax rates, consistency and transparency in the classification of motor vehicles, and compliance with the principles of the Harmonised Commodity Description and Coding System. Given its systematic presentation of determining characteristics, the table serves as a practical reference for both customs authorities and foreign trade operators, supporting the effective and legally compliant performance of customs procedures.

The object of identification "car" can be represented as a set of characteristics expressed as fuzzy statements. A fuzzy statement is a sentence about which one can judge the degree of its truth or falsehood at a given time. The degree of truth or falsehood of each fuzzy statement takes on a value from the closed interval [0; 1], where 0 and 1 are the limiting values of the degree of truth and coincide with the concepts of "false" and "true" for "clear" statements. A fuzzy statement that has a value of the degree of truth equal to 0.5 is called indifference, since it is true to the same extent as it is false. Compound sentences are formed from simple sentences using the logical operations of negation, conjunction, disjunction, implication, etc. Thus, the conditional car of commodity heading 8703 can be written as a set of vague sentences that meet certain characteristics (Table 2).

Table 2. Characteristics of heading 8703

Unclear statement	$\tilde{a}_1$	$\tilde{a}_{12}$	$\tilde{a}_{13}$	$\tilde{a}_{21}$	$\tilde{a}_{22}$	$\tilde{a}_3$	$\tilde{a}_4$
Degree of authenticity	0.9	0.7	0.9	0.6	0.4	0.6	0.9

Source: developed by the authors

The features relevant for classifying products in the subcategories 8703 23 11 30 and 8703 23 19 30 have been identified. To determine whether a product belongs to the specified product groups, the following characteristics are important: $\tilde{a}_4$, $\tilde{a}_{21}$, $\tilde{a}_{22}$, $\tilde{a}_3$, $\tilde{a}_{13}$. A concise, generalised statement characterising the proposed product subcategories can be formulated as follows:

$$\tilde{A}_{8703231930} = (\tilde{a}_{13} \,\&\, ((\tilde{a}_{21} U \tilde{a}_{22})\; U \neg \tilde{a}_3))\;\&\tilde{a}_4;$$
$$\tilde{A}_{8703231130} = (\neg \tilde{a}_{13} \& ((\tilde{a}_{21} U \tilde{a}_{22})\; U \neg \tilde{a}_3))\;\&\tilde{a}_4. \qquad (1)$$

The degrees of truth for the first and second fuzzy statements are determined. Using the definition, they can be written as follows:

$$\tilde{A}_{8703231930} = (\tilde{a}_{13} \,\&\, ((\tilde{a}_{21} U \tilde{a}_{22})\; U \neg \tilde{a}_3))\;\&\tilde{a}_4;$$
$$\tilde{A}_{8703231930} = (\tilde{a}_{13} \& \max(\max(\tilde{a}_{21}, \tilde{a}_{22}), \neg \tilde{a}_3))\;\&\tilde{a}_4;$$
$$\tilde{A}_{8703231930} = \min(\min(\tilde{a}_{13}, \max(\max(\tilde{a}_{21}, \tilde{a}_{22}), \neg \tilde{a}_3)), \tilde{a}_4);$$
$$\tilde{A}_{8703231930} = \min(\min(0.9, \max(\max(0.6, 0.4), 1-0)), 0.9) = 0{,}9. \qquad (2)$$

$$\tilde{A}_{8703231130} = (\neg \tilde{a}_{13} \& ((\tilde{a}_{21} U \tilde{a}_{22})\; U \neg \tilde{a}_3))\;\&\tilde{a}_4;$$
$$\tilde{A}_{8703231130} = (\neg \tilde{a}_{13} \& \max(\max(\tilde{a}_{21}, \tilde{a}_{22}), \neg \tilde{a}_3))\;\&\tilde{a}_4;$$
$$\tilde{A}_{8703231130} = \min(\min(1-\tilde{a}_{13}, \max(\max(\tilde{a}_{21}, \tilde{a}_{22}), \neg \tilde{a}_3)), \tilde{a}_4);$$
$$\tilde{A}_{8703231130} = \min(\min(1–0.9, \max(\max(0.6, 0.4), 1-0)), 0.9) = 0.1. \qquad (3)$$

So, based on the calculation results, it can be concluded that a car with the given characteristics is far more appropriately classified under code 8703 23 19 30 rather than under code 8703 23 11 30. The Table 3 is completed following the procedure for determining product codes in accordance with the UKTZED.

Table 3. The structure of the product respectively UKTZED (extract)

Code	Product description
8703	Motor vehicles and other motorised transport vehicles, designed primarily for the transport of persons (other than motor transport vehicles of heading 8702), including trucks, vans and racing cars:
8703 10 18 00	- - others
……………	- other compact tools with an internal combustion engine with spark ignition and with a crank-rod mechanism:
8703 21 10 00	- - - new ones
8703 21 90	- - - what was used:
8703 21 90 10	- - - - no more than 5 years
8703 21 90 30	- - - - more than 5 years
8703 22	- - with a side volume of engine cylinders over 1.000 cm^3, but not more than 1,500 cm^3:
8703 22 10 00	- - - new ones
8703 22 90	- - - what is the meaning of the word:
8703 22 90 10	- - - - no more than 5 years
8703 22 90 30	- - - - more than 5 years
8703 23	- - with a lateral volume of engine cylinders over 1,500 cm^3, but not more than 3,000 cm^3: - - - new
8703 23 11	- - - - motor vehicles equipped for temporary human consumption:
8703 23 11 10	- - - - - with engine cylinder volume over 1,500 cm^3, but not more than 2,200 cm^3
8703 23 11 30	- - - - - with an engine cylinder volume of more than 2,200 cm^3, but not more than 3,000 cm^3
8703 23 19	- - - - others:
8703 23 19 10	- - - - - with engine cylinder volume over 1,500 cm^3, but not more than 2,200 cm^3
8703 23 19 30	- - - - - with a volume of more than 2,200 cm^3, but not more than 3,000 cm^3

Note: Hyphens in the structure of the UKTZED are used to indicate the hierarchical level of product classification. Each additional hyphen represents a lower-level subheading within the corresponding product category and specifies the characteristics of the goods
Source: developed by the authors

Table 3 contained systematic information on the product nomenclature of vehicles under the UKT FEA code 8703, which covers passenger cars and other motor vehicles designed primarily for the transport of passengers. This structure presented a hierarchical division of product positions based on the key technical characteristics of vehicles, including the type of engine and method of ignition, the presence of a crank mechanism, engine cylinder capacity, classification into new and used, and breakdown by service life (up to 5 years and over 5 years). It reflects that each basic code (e.g., 8703, 8703 21, 8703 22, 8703 23) comprises a number of subcategories that specify the technical parameters of the vehicle. This hierarchical structure is typical for the UKT FEA and enables accurate tariffing as well as the correct determination of tax rates depending on the vehicle's configuration, technical condition, and age. The positions regarding vehicles are presented in particular detail, including those with a spark-ignition (gasoline) engine, with an engine displacement of up to 1,500 cm^3, 1,500-2,200 cm^3, and 2,200-3,000 cm^3, and those which are new as well as used. Such detailing is important for customs clearance, as different subcategories are subject to varying rates of customs duties, excise duties, and other taxes. Table 3 also demonstrates the logic of vehicle classification in customs matters, progressing from a general code to the most detailed description of the goods. The possibility of identifying objects of customs control for commodity item 2710, according to the UKTZED (object class "motor gasoline"), is examined using the mathematical apparatus of fuzzy logic (Table 4).

Table 4. Characteristics determining for classification of product

$\tilde{a}_1$	"Easy children for other purposes"
$\tilde{a}_{21}$	"Fuel for active engines"
$\tilde{a}_{22}$	"Aviation gasoline"
$\tilde{a}_{23}$	"Other gasolines containing lead"
$\tilde{a}_{31}$	"With octane number less than 95"
$\tilde{a}_{32}$	"With an octane number of 80 or less with a content of not less than 5 wt.% of a high-octane oxygen-containing additive or ethyl tert-butyl ether or its mixture"
$\tilde{a}_4$	"Other"

Source: developed by the authors

Table 4 showed the systematisation of the classification features of goods used to determine their belonging to the relevant UKTZED codes during customs clearance. The table presents the symbols of the characteristics of goods that are decisive for their correct identification in accordance with the requirements of the Harmonised Commodity Description and Coding System (World Customs Organization, n.d.). The presented classification features cover the following groups of characteristics:

- functional purpose of the goods (for example, "for other purposes");
- type and characteristics of fuel, in particular gasoline;
- octane number, which is a key parameter for the classification of petroleum products;
- content of additives, including high-octane oxygen-containing components (ethyl tertiary-butyl ether (ETBE) and other additives).

Each of the above characteristics is assigned a specific symbol, which facilitates subsequent analysis and the use of data in customs practice. For instance, subgroups representing different types of gasoline are distinguished by octane number and impurity content, allowing the product to be unambiguously attributed to the corresponding commodity subheading. The structure of the table demonstrates a logical approach to the classification of goods, progressing from a general characteristic, such as the product type, to narrower characteristics that specify the physical and chemical properties. This format of presenting information is particularly valuable in the customs control process, as it helps prevent errors in determining the commodity code, enables the reasonable application of the appropriate duty and excise tax rates, ensures a consistent approach to the classification of petroleum products, and facilitates accurate and transparent tariff regulation. Owing to its clear structure and the generalisation of essential classification indicators, the table can serve as a reference tool both in academic research, such as a thesis, and in the practical activities of customs authorities and foreign trade entities. Therefore, in accordance with the UKTZED, the company's trade code: 8703 23 19 30 is a railway vehicle with an internal combustion engine with spark ignition and a crank-rod mechanism, new, other, with engine cylinder volume over 2,200 cm³, but not more than 3,000 cm³. The object of identification "motor gasoline" can be considered as a collection of abstract, vague expressions. Thus, the conditional motor gasoline of heading 2710 can be represented as a set of fuzzy expressions corresponding to specific specifications (Table 5).

Table 5. Characteristics of heading 2710

Vague expression	$\tilde{a}_1$	$\tilde{a}_{21}$	$\tilde{a}_{22}$	$\tilde{a}_{23}$	$\tilde{a}_{31}$	$\tilde{a}_{32}$	$\tilde{a}_4$
Degree of ownership	0.85	0.3	0.4	0.8	0.3	1	0

Source: developed by the authors

The features relevant for classifying the company in the subcategories 2710 11 41 11 and 2710 11 41 19 are identified. To determine the company's assignment, the following abstract indicators are significant for the specified social groups: ã32, ã21, ã22, ã23, and ã1. A complex fuzzy statement can then be formulated to summarise the proposed social subcategories:

$$\tilde{A}_{2710114111} = (\tilde{a}_{32} \,\&\, ((\tilde{a}_{22} U \tilde{a}_{23})\ U \neg \tilde{a}_{21}))\ \&\tilde{a}_1;$$
$$\tilde{A}_{2710114119} = (\neg \tilde{a}_{32} \& ((\tilde{a}_{22} U \tilde{a}_{23})\ U \neg \tilde{a}_{21}))\ \&\tilde{a}_1. \quad (4)$$

The degrees of truth for the first and second fuzzy expressions are determined. Using the definition, they can be written as follows:

$$\tilde{A}_{2710114111} = (\tilde{a}_{32} \& ((\tilde{a}_{22} U \tilde{a}_{23})\ U \neg \tilde{a}_{21}))\ \&\tilde{a}_1;$$
$$\tilde{A}_{2710114111} = (\tilde{a}_{32} \& \max(\max(\tilde{a}_{22},\ \tilde{a}_{23}), \neg \tilde{a}_{21}))\ \&\tilde{a}_1;$$
$$\tilde{A}_{2710114111} = \min(\min(\tilde{a}_{32},\ \max(\max(\tilde{a}_{22},\ \tilde{a}_{23}), \neg \tilde{a}_{21})), \tilde{a}_1);$$
$$\tilde{A}_{2710114111} = \min(\min(1,\ \max(\max(0.4,\ 0.8),\ 1-0.3)),$$
$$0.85) = 0{,}8. \quad (5)$$
$$\tilde{A}_{2710114119} = (\neg \tilde{a}_{32} \& ((\tilde{a}_{22} U \tilde{a}_{23})\ U \neg \tilde{a}_{21}))\ \&\tilde{a}_1;$$
$$\tilde{A}_{2710114119} = (\neg \tilde{a}_{32} \& \max(\max(\tilde{a}_{22},\ \tilde{a} =_{23}), \neg \tilde{a}_{21}))\ \&\tilde{a}_1;$$
$$\tilde{A}_{2710114119} = \min(\min(1-\tilde{a}_{32},\ \max(\max(\tilde{a}_{22},\ \tilde{a}_{2=3}), \neg \tilde{a}_{21})),\ \tilde{a}_1);$$
$$\tilde{A}_{2710114119} = \min(\min(1-1,\ \max(\max(0.4,\ 0.8),\ 1-0.3)),$$
$$0.85) = 0. \quad (6)$$

Therefore, taking into account the calculation results, motor gasolines with the specified characteristics are more appropriately classified under code 2710 11 41 11 rather than under code 2710 11 41 19. In accordance with the UKTZED, the corresponding company codes are identified and shown in Table 6.

The Table 6 presented a multi-level structure of the classification of petroleum products under code 2710, which covers petroleum distillates and motor gasolines. The differentiation of product subcategories is based on their physico-chemical properties, which directly influence their applicability, environmental impact, energy performance, and the regulatory requirements for their transport and taxation. The structure illustrated a clear sequence of classification levels, beginning with the general product category 2710, which covers petroleum and bituminous mineral products, and then narrowing to subcategory 2710 11, which includes light distillates such as motor gasolines. Further subdivisions are made according to the purpose of the product (for other purposes, special gasolines, or motor gasoline), the type of gasoline (aviation, leaded, or unleaded), the presence or absence of lead, octane rating, and the content of high-octane oxygenated additives, such as ETBE. This hierarchical structure ensured the accurate assignment of each product to the appropriate tariff heading based on its essential characteristics. Special gasolines are intended for laboratory, technical, or specific industrial applications, whereas motor gasolines are designed for use in internal combustion engines. This distinction affects taxation, customs payments, and labeling requirements. Leaded gasolines form a separate category because their use is strictly regulated or prohibited due to environmental concerns, while unleaded gasolines are classified independently in compliance with international emission standards. The octane number serves as a primary classification criterion, defining the fuel's resistance to detonation. Fuels are distinguished, for example, between those with less than 95 octane and those with 80 octane or less. The octane number determines the suitability of fuel for specific engine types and ensures compliance with quality and environmental regulations. Subcategory 2710 11 41 11 additionally specifies a requirement of at least 5 wt.% of a high-octane oxygen-containing additive or ETBE. Such additives are significant because they increase the octane rating, reduce the toxicity of exhaust gases, modify key physico-chemical parameters of gasoline, and influence the taxation system, particularly excise duty rates.

Table 6. Structure of UKTZED (part)

Code	Social experience
2710	Petroleum or petroleum products derived from bituminous dust (minerals), including white; products, not otherwise specified, containing 70 wt.% or more of oil or oil products derived from bituminous dust (minerals), because these oil products are the main structural components of the products; manufactured oil products:
2710 11	- - easy to read:
……………..	- - - for other purposes
	- - - - special gasolines:
2710 11 25 00	- - - - - others
	- - - - others:
	- - - - - motor gasoline:
2710 11 31 00	- - - - - - aviation gasoline
	- - - - - - others, containing lead:
	- - - - - - - 0,013 g/l or less:
2710 11 41	- - - - - - - - with octane number less than 95:
	- - - - - - - - - with an octane number of 80 or less:
2710 11 41 11	- - - - - - - - - - with a content of not less than 5 wt.% of high-octane oxygen additive or ethyl tert-butyl ether or its mixture
2710 11 41 19	- - - - - - - - - - others

Source: developed by the authors

Therefore, fuels containing these additives are classified separately. Classification based on octane rating and additive content is crucial for several reasons:

1. Internal combustion engines are designed to operate with fuel of a specific octane value, and using unsuitable fuel can lead to detonation, reduced engine efficiency, and mechanical damage, making proper classification essential.

2. Environmental and regulatory requirements, such as modern Euro emission standards, demand high-octane fuel with minimal harmful impurities. The presence or absence of lead alters the environmental impact of the fuel, while oxygenated high-octane additives ensure compliance with environmental regulations.

3. Fiscal and customs considerations are influenced by additive content, as substances like ETBE affect applicable excise duties, and different octane categories are taxed differently. Correct classification ensures accurate calculation of customs duties and taxes.

4. Market value is also affected, with high-octane fuels and additive-enriched gasolines differing significantly in price and market characteristics, influencing customs valuation.

The Table 6 thus presented a detailed and logically structured classification system for petroleum products, enabling precise identification based on physico-chemical characteristics. Distinctions between subcategories are grounded in parameters that determine the quality, safety, application area, and tax regime of each fuel type. For this reason, characteristics such as octane rating and the presence of high-octane oxygenated additives are essential for correctly determining the tariff code under UKTZED. Therefore, in accordance with UKTZED, the company's product code: 2710 11 41 11 – light diesel, for other purposes: motor gasoline, with an octane number of 80 or less, with a content of no less than 5 wt.% of high-octane oxygen additive or ethyl tert-butyl ether or its mixture. The mathematical model of digitisation of customs clearance processes using fuzzy logic in international freight transport is presented, which will significantly improve the accuracy of declarations and speed up customs procedures.

Discussion

The results obtained in this study demonstrated that the proposed fuzzy-logic-based model significantly enhances the efficiency, adaptability, and analytical capacity of customs procedures, particularly under conditions of uncertainty that are inherent to global logistics chains. The developed mathematical model for verifying the correctness of customs declarations has practical significance and can be used in customs control methods. This distinguishes the work from other developments, which have a number of shortcomings. The results of the present study align with the I.M. Kveliashvili & T.S. Totska (2021) conclusions, indicating that the strategic objectives of customs authorities focus on the implementation of innovations and information and communication technologies, the improvement of procedural formalities, and the adoption of management decisions grounded in the rule of law and aimed at ensuring customs security. The findings correlate strongly with the trends identified in contemporary transport-systems research. As emphasised by E.M. Demchenko & O.E. Dorosh (2023) and Yu.O. Osipchuk (2024), the ongoing transformation of logistics networks is driven by digital integration, smart transport systems, and automated data exchange. The present study supports this perspective by showing that customs clearance is also increasingly dependent on digital ecosystems that must process heterogeneous, dynamic, and often incomplete transport information. The methodological foundation of the model aligns with earlier works on fuzzy-logic applications in transport analytics. Yu.O. Kovtunov *et al.* (2020) demonstrated that fuzzy methods improve the algorithmisation of interactive monitoring processes by compensating for uncertain or incomplete data. In this research, fuzzy inference is similarly applied to classify customs-related risks, interpret inconsistent documentation, and integrate diverse data flows coming from transport monitoring systems and logistics operators. A close conceptual match is also seen with studies analysing digital customs risk-management systems. V.F. Tyshchenko *et al.* (2022) highlighted the use of fuzzy algorithms within automated system for customs clearance of goods and vehicles/automated system for risk analysis and management for constructing complex risk profiles. The results of this study extend those findings by offering a generalised fuzzy-logic model suitable for real-time customs clearance, enabling dynamic adjustment of risk indicators and prioritisation of consignments. This strengthens the argument that fuzzy logic provides a more human-interpretable and flexible alternative to purely statistical risk models. The work further aligns with M. Ishchuk *et al.* (2024), who examined the modernisation of the Ukrainian Customs Service, particularly emphasising automated risk analysis and the growing role of AI-based tools. The model developed in this study contributes to that modernisation pathway, proposing an adaptable decision-support mechanism that reduces manual workload, increases transparency, and supports harmonisation with European Union digital-customs standards. As noted in the analysis of information and communication technology-based customs systems in Korea by S.-B. Kim & D. Kim (2020), digital transformation improves transparency, accelerates customs processes, and enhances institutional efficiency. The findings of the article reinforce this conclusion: the fuzzy-logic model reduces subjective decision-making, strengthens rule-based processing, and enables faster identification of potentially risky shipments. From the standpoint of logistics and transport-operations optimisation, the results are consistent with studies demonstrating the robustness of fuzzy-logic decision tools.

A. Pálková & J. Mašek (2024) showed that fuzzy models effectively evaluate uncertain transport parameters and assist in selecting optimal logistics solutions. In the current research, fuzzy decision rules support the interpretation of ambiguous cargo characteristics, varying routes, and mixed transport conditions – factors that directly influence customs-risk scoring. Similarly, advanced fuzzy-logic techniques used in logistics modelling, such as those applied by D.P. Moreno-Palacio *et al.* (2023) to freight tour optimisation, validated the relevance of fuzzy constraints in environments with variable or unpredictable demand. The proposed model leverages comparable fuzzy-logic logic structures to manage unpredictability in international cargo flows and irregularities in customs documentation. In turn, B. Chen *et al.* (2021) developed a machine-learning model aimed at detecting HS-code misclassification in customs declarations. The study demonstrated that the application of data-driven algorithms enhanced the accuracy of customs control procedures and reduced the risk of classification errors. Finally, the results resonate with broader risk-assessment studies in transport and supply-chain systems. D. Muzylyov *et al.* (2024) demonstrated the effectiveness of fuzzy methods for evaluating operational uncertainty in agricultural logistics chains. This reinforces the argument that fuzzy logic is a versatile tool applicable across different sectors of freight movement – including customs clearance, where risks are multidimensional and dynamic. Overall, the results of this study confirm that incorporating fuzzy logic into the digital architecture of customs-clearance processes offers several significant benefits:

- enhanced processing of uncertain, incomplete, or contradictory data;
- greater flexibility and transparency in risk-assessment procedures;
- better integration with modern transport-monitoring and ICT platforms;
- higher overall efficiency and reduced clearance times;
- alignment with global trends in digital customs transformation.

The convergence of evidence from related works and the empirical findings of this study indicate that fuzzy-logic-based customs models can serve as a foundational element of next-generation digital customs systems, especially in international freight transportation where uncertainty, complexity, and operational variability remain critical challenges. The identification of objects of customs clearance with the calculation of fuzzy logic allows automating the processing of information provided in the cargo customs declaration, procurement documents and technical documentation, which is submitted to the customs authorities with the control of the right to classify goods with the help of unclear logicians. The automated system issues recommendations, approvals and recommendations for customs clearance of goods, and also saves time for customs clearance. An automated expert system for determining the correctness of customs clearance of goods is intended to strengthen control over the accurate classification of goods, prevent cases of tax evasion and violations of non-tariff regulations by participants in foreign economic activity, reduce the time required for customs clearance, and enable the resolution of complex and conflicting issues that arise during classification. Additionally, it minimises errors in assigning the correct commodity codes, ensuring compliance with customs procedures and regulatory requirements.

Conclusions

It is shown that the identification of objects of customs clearance with the calculation of the fuzzy logic algorithm allows automating the processing of the information entered in the cargo customs declaration, packaging documents and technical documentation. and which is submitted to the customs authorities with the control of the right to classify goods with the help of fuzzy logic. The automated system issues recommendations, approvals and recommendations for customs clearance of goods, and also saves time for customs clearance. A mathematical model for checking the correctness of customs clearance with the use of fuzzy logic in international cargo transportation has been developed. Automated experimental system for determining the correctness of the customs clearance of goods, which should provide: the purpose of control of the correctness of the classification of goods under customs duty permission; prevention of attempts by students to enhance external economic activity from paying taxes in full and from non-tariff adjustment measures when violations are committed declaration of goods moving through the customs territory of Ukraine; the beginning of the customs clearance of the company; direct resolution of complex and very serious problems with the classification of goods that arise during customs clearance; avoiding errors in the classification of goods. The developed mathematical model for checking the correctness of customs clearance with the calculation of fuzzy logic must become a part of the risk management system that arises during the declaration of goods. It will also be possible to improve the risk management system by building a more balanced methodology for determining the multiple value of the risk assessment of customs procedures.

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Conflict of Interest

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References

[1] Berestov, I., Shelehan, H., & Berestova, T. (2022). Digitalization of customs control processes and customs clearance of cargo on railway transport. *Central Ukrainian Scientific Bulletin. Technical Sciences*, 5(36), 291-297. doi: 10.32515/2664-262X.2022.5(36).

[2] Chen, B., van Rijnsoever, F.J., Molenhuis, M., van Dijk, D., Tan, Y.-H., & Rukanova, B. (2021). The use of machine learning to identify the correctness of HS code for the customs import declarations. In *2021 IEEE 8th international conference on data science and advanced analytics (DSAA)*. New York: IEEE. doi: 10.1109/DSAA53316.2021.9564203.

[3] Chupailenko, O.A., Bilokur, M.V., & Polishchuk, R.V. (2023). Identification of transport and customs risks in international freight transportation using the expert assessment method. *Scientific Notes of V.I. Vernadsky TNU. Series: Technical Sciences*, 34(73), 329-335. doi: 10.33744/2308-6645-2022-3-53-409-426.

[4] Demchenko, E.M., & Dorosh, O.E. (2023). Transport systems and transportation technologies. *Collection of Scientific Works of DNUZT*, 25, 70-83. doi: 10.15802/TSTT2023/284496.

[5] Dong, Z., & Tian, M. (2025). Fuzzy logic-based risk assessment model for cross-border e-commerce logistics supply chain. *Journal of Circuits, Systems and Computers*. doi: 10.1142/S0218126626500453.

[6] In 2024, customs authorities of the State Customs Service detected violations of customs regulations amounting to UAH 18 billion. (2025). Retrieved from https://customs.gov.ua/news/zagalne-20/post/za-2024-rik-mitnitsi-derzhmitsluzhbi-viiavili-porushen-mitnikh-pravil-na-18-mlrd-grn-1967.

[7] Ishchuk, M., Ishchuk, O., & Khrypko, S. (2024). Sustainable digital evolution: Transforming the Ukrainian customs service. *European Journal of Sustainable Development*, 13(1), 217-228. doi: 10.14207/ejsd.2024.v13n1p217.

[8] Ivashova, L.M., & Kyda, L.I. (2020). Digitalization of customs procedures: The current state and prospects of customs development. *Public Administration and Customs Administration*, 3(22), 218-230. doi: 10.32836/2310-9653-2019-3-218-230.

[9] Kim, S.-B., & Kim, D. (2020). ICT implementation and its effect on public organizations: The case of digital customs and risk management in Korea. *Sustainability*, 12(8), article number 3421. doi: 10.3390/su12083421.

[10] Kostiana, O.V., Karpova, V.V., & Ostapenko, V.M. (2021). Risk management in customs affairs as a factor in ensuring customs security in a period of economic downturn. *Business Inform*, 11, 404-410. doi: 10.32983/2222-4459-2021-11-404-410.

[11] Kovtunov, Yu.O., Makohon, O.A., Isakov, O.V., Babkin, Yu.V., Kalinin I.V., & Lazuta, R.R. (2020). Use of the mathematical apparatus of fuzzy logic for fuzzification and algorithmization of the interactive monitoring system of transport communications. *Control, Navigation and Communication Systems*, 3(61), 64-68. doi: 10.26906/SUNZ.2020.3.064.

[12] Kveliashvili, I.M., & Totska, T.S. (2021). Implementation of modern customs management concepts of European countries into national practice. *Public Administration in the Sphere of State Security and Customs Affairs*, 2(29), 74-80. doi: 10.32836/2310-9653-2021-2.12.

[13] Law of Ukraine No. 2697-IX "About the Customs Tariff of Ukraine". (2023, January). Retrieved from https://zakon.rada.gov.ua/laws/show/2697-20?lang=en#Text.

[14] Lebid, V., Anufrieva, T., & Savenko, G. (2020). Studies of the efficiency of simplification of customs formalities on the basis of digitalization. *Technological Audit and Production Reserves*, 1(4(57)), 49-53. doi: 10.15587/2706-5448.2021.225627.

[15] Lemeha, R. (2020). Automation and informatization of customs procedures as priority directions of improvement of administration of customs regimes in Ukraine. *Entrepreneurship, Economy and Law*, 11, 126-133.

[16] Luo, N., Yu, H., You, Z., Li, Y., Zhou, T., Jiao, Y., Han, N., Liu, C., Jiang, Z., & Qiao, S. (2023). Fuzzy logic and neural network-based risk assessment model for import and export enterprises: A review. *Journal of Data Science and Intelligent Systems*, 1(1), 2-11. doi: 10.47852/bonviewJDSIS32021078.

[17] Mishchenko, A.V., Kurylo, O.V., & Zolotukhina, O.A. (2020). A fuzzy model for assessing information security risks and maintaining the protection level of ERP systems. *Telecommunication and Information Technologies*, 1(66), 142-150. doi: 10.31673/2412-4338.2020.011451.

[18] Moreno-Palacio, D.P., González-Calderón, C.A., López-Ospina, H., Gil-Marin, J.K., & Posada-Henao, J.J. (2023). Freight tour synthesis based on entropy maximization with fuzzy logic constraints. *Transportation*, 51, 2323-2357. doi: 10.1007/s11116-023-10407-y.

[19] Muzylyov, D., Medvediev, I., & Pavlenko, O. (2024). Risk factor assessment in agricultural supply chain by fuzzy logic. *IOP Conference Series: Earth and Environmental Science*, 1376(1), article number 012038. doi: 10.1088/1755-1315/1376/1/012038.

[20] Osipchuk, Yu.O. (2024). Risk management in customs affairs under martial law conditions. *Economics. Management. Current Issues of Science and Practice*, 2(108), 16-21. doi: 10.26642/ema-2024-2(108)-16-21.

[21] Pálková, A., & Mašek, J. (2024). Fuzzy logic as a decision-making tool for transport request selection. *Transportation Research Procedia*, 77, 116-122. doi: 10.1016/j.trpro.2024.01.015.

[22] Tyshchenko, V.F., Ostapenko, V.M., & Karpova, V.V. (2022). Digitization in the customs risk management. *Economics and Society*, 37, 60-65. doi: 10.32782/2524-0072/2022-37-35.

[23] Vijayakumar, S. (2025). Technology-centric and data-driven customs risk management for supply chain security. *World Customs Journal*, 19(1), 38-63. doi: 10.55596/001c.131745.

[24] World Customs Organization. (n.d.). *Overview*. Retrieved from https://www.wcoomd.org/en/topics/nomenclature/overview.aspx.

[25] Zheng, C., Cao, J., & Zhou, H. (2025). Optimization of emergency supplies customs clearance strategy based on K-means clustering. *Frontiers in Public Health*, 13, article number 1481328. doi: 10.3389/fpubh.2025.1481328.

Цифровізація процесів митного оформлення товарів з розрахунком математичної моделі нечіткої логіки

Георгій Прокудін
Доктор технічних наук, професор
Національний транспортний університет
01010, вул. М. Омеляновича-Павленка, 1, м. Київ, Україна
https://orcid.org/0000-0001-9701-8511

Олексій Чупайленко
Кандидат технічних наук, доцент
Національний транспортний університет
01010, вул. М. Омеляновича-Павленка, 1, м. Київ, Україна
https://orcid.org/0000-0002-4837-0727

Юрій Колесник
Аспірант
Національний транспортний університет
01010, вул. М. Омеляновича-Павленка, 1, м. Київ, Україна
https://orcid.org/0000-0002-8079-9961

Аркадій Козлов
Доцент
Національний транспортний університет
01010, вул. М. Омеляновича-Павленка, 1, м. Київ, Україна
https://orcid.org/0000-0002-0170-7222

Дмитро Свірін
Доцент
Національний транспортний університет
01010, вул. М. Омеляновича-Павленка, 1, м. Київ, Україна
https://orcid.org/0000-0001-5860-4446

Михайло Головатюк
Асистент
Національний транспортний університет
01010, вул. М. Омеляновича-Павленка, 1, м. Київ, Україна
https://orcid.org/0009-0005-0331-0105

Анотація. Актуальність дослідження зумовлена зростаючим використанням автоматизованих систем митного оформлення, які формують рекомендації, попередження та обґрунтування з метою скорочення часу обробки вантажів. Водночас ефективність таких систем залежить від науково обґрунтованої методології визначення оптимальної періодичності перегляду профілів ризику та вдосконалення кількісної оцінки ризиків. Метою дослідження було розроблення математичної моделі перевірки правильності митного оформлення із застосуванням апарату нечіткої логіки в умовах міжнародних вантажних перевезень. Методи дослідження включали розроблення математичних моделей та алгоритмів їх реалізації. Зокрема, математичний апарат нечіткої логіки було застосовано для визначення коректності митного оформлення товарів. Показано, що ідентифікація об'єктів митного контролю із використанням нечіткої логіки дозволяє автоматизувати обробку інформації, поданої в митній декларації, супровідних документах і технічній документації, яка надходить до митних органів для контролю правомірності класифікації товарів. Розроблено рекомендації щодо використання апарату нечіткої логіки в автоматизованій експертній системі для визначення правильності митного оформлення. Запропонована система спрямована на посилення контролю за коректністю класифікації товарів під час митного оформлення, запобігання ухиленню учасників зовнішньоекономічної діяльності від повної сплати податків та дотримання заходів нетарифного регулювання шляхом порушення правил декларування товарів, що переміщуються через митний кордон України. Вона також орієнтована на скорочення часу митного оформлення, безпосереднє вирішення складних і суперечливих класифікаційних питань та уникнення помилок у класифікації товарів

Ключові слова: автоматизація інформації; управління ризиками; нетарифне регулювання; логістичні оператори; транспортний моніторинг