1. Introduction

The European Union expansion has led to significant changes in the political and economic conditions for the further broadening of Ukraine’s cooperation with the EU countries and created favorable conditions for gradual integration into the world economic system. The international transport corridors that pass through the territory of Ukraine, the national transport system as one of leading sectors of the national economy make a considerable contribution to the success of these processes [1, 2]. The plans for development of relations between the EU and Ukraine have enabled transition from cooperation to gradual economic integration and deepening of political cooperation. Integration of Ukraine’s transport system into European structures becomes of particular relevance and implies further improvement of transport technologies and coordination with production, trade, warehouse and customs technologies [3].

Effective functioning of the transport sector is a necessary condition for stabilization, structural transformation of the national economy, development of foreign economic activities, satisfaction of the needs of population and social production in transportation and protection of Ukrainian economic interests. The main functions of the transport system invariably include ensuring unity of national goods markets, interconnection of regions, mobility of citizens, meeting the transportation needs of foreign trade [3].

A number of important tasks arise in the field of integration of the domestic transport system into European and international transport systems. It is necessary to reason-
2. Literature review and problem statement

Analysis of the main lines of the Ukrainian transport strategy indicates a number of problems related to the technical condition, level of technological and informational support of the sector, customer service, use of geopolitical advantages of the country, etc. Effective measures should be taken to ensure economic and transport and technological security of foreign economic activity to increase efficiency of international transportation. This will allow Ukraine to successfully integrate into European economic space and grow volumes of export-import cargo traffic [4].

For successful development of the Ukrainian transport system, it is necessary to apply logistic approaches in solving the sector problems. Multimodal, intermodal and combined transportation systems represent modern logistics concepts aimed at improvement of the package of services provided in the process of cargo movement from supplier to consumer. The active use of new concepts in logistics will improve the overall efficiency of the transport and logistics processes. Development of current concepts of traffic management in transport and logistics systems is considered in [5–10]. However, despite a significant number of scientific works devoted to studying the problems of improving the transportation process, elucidation of this problematics cannot be considered finally completed.

With the advent and active development of information technologies and computer systems, development of scientific approaches to modeling the processes of management of transportation and logistics systems is based on a multifactor analysis of technical, technological and logistics indicators.

Modeling of Ukrainian foreign economic activity to determine main routes of international cargo traffic and ensure further development based on the factor analysis of cargo flows is presented in [11]. The main factors influencing the formation of the indicator of efficiency of container traffic were determined in [6]. However, it is necessary to develop a systems approach to the analysis of problems of transport and logistics systems [12]. Theoretical and methodological fundamentals of factor analysis of competitiveness of international motor freight are generalized and scientists' views concerning classification of the factors influencing development of international motor freight are analyzed in [13]. Improvement of methodological bases for assessing the state of financial and economic security of haulers taking into account the sector specifics on the basis of its modeling by factor analysis was set forth in [14].

In spite of the examples of successful application of the factor analysis methods in solving concrete problems in the study of complex multifactor systems, one should note the fundamental difficulty arising in application of this analysis. With the use of a multidimensional correlation matrix taking into account statistical relationships between factors, the factor analysis makes it possible to reduce the problem with a large number of influencing factors to analysis of simpler models with fewer factors which are linear combinations of source factors. The problem consists in a correct and adequate identification of the obtained synthesized factors. It cannot be solved successfully each time. Besides, correct application of the methods of factor analysis in the given problem is practically impossible for the following reason. The peculiarity of this task is that the statistical material used for analysis is a set of deterministic costs of the factors of the transport and logistic process which excludes the possibility of correct construction of a correlation matrix. Data accumulated for this purpose in several years do not save the situation because the fundamental principle of the probability theory, that is integrity and invariability of the mechanism and conditions for formation of the observed quantities is violated under conditions of the present-day market economy.

Other approaches to investigation of road freight and other multifactor processes and systems are known, in particular, the hierarchy analysis method. Application of systems analysis based on the hierarchy analysis method in the theory of decision-making, application of the hierarchy analysis method for solution of multifactor problems is given in the papers [5, 15–17]. The method well-known in the decision-making theory is very effective in making decisions under conditions of a large number of influential factors. Also, this method of systems analysis can be successfully applied in cases where a decision maker is forced to turn to the expert opinion because of lack of competence or for other reasons [15]. The procedure for determining effective means of cargo transportation of any type that meet requisite requirements using the hierarchy analysis method and paired comparisons, is proposed in [16]. A complex analytical indicator characterizing dynamics of international goods turnover for certain groups of goods was formed in [5] using the hierarchy analysis method based on the results of factor analysis of statistical data. The possibility of using the hierarchy analysis method and its simplified version for solving multifactor problems is proposed in [17]. However, this approach does not take into account modern methods of logistic analysis.

A wide range of works are devoted to theoretical aspects of the problem of classification, in particular, objects of transport and logistics systems. Classification methods enable division of the set of objects or observations into a priori groups, so-called classes. Inside each group, objects are considered similar to each other and have approximately the same properties and attributes. In this case, solution is based on the analysis of the costs of attributes.

Classification is one of the most important among the problems of data mining and covers a variety of applications including logistics, marketing, image recognition, medical diagnostics, and more. The classification methods are used in transportation and logistics systems when assessing the state of infrastructure objects, transport and logistics services, in analysis of cargo flows, etc.

Theoretical foundations and classification algorithms are considered in [18–20]. The use of information technology and intelligent models in the problems of classification in various fields of people's activity is described in [21–24]. Analysis of neural network methods for solving the clas-
sification problem is presented in [25–29]. Mathematical
the problem presented in the form of
discrete, non-smooth and multi-extreme optimization prob-
lems are considered in [18] for solving individual problems of
recognition and analysis of data.

Various models of the algorithms intended for solving
classification problems according to categorical features are
considered in [19]. Both the simplest generalizations of clas-
sical algorithms and fundamentally new generalizations are
considered: coding for the use of random forests and gener-
alization of proximity-based algorithms.

Structure of the Statistica application package, methods
of cluster, factor and discriminant analyses, implementation
of the described methods of multifactor statistical analysis in
this package are given in [20].

Various classifications of reverse flows of goods by
spheres of circulation, production and consumption are
given in [21]. Classification of conditions of reliability of the
railroad tracks by allowable deviations during laying and
maintenance of the track was made in [22]. Necessity of nor-
malizing technical conditions of the ballast cross section and
the ballast bed for the developed classification was estab-
lished. The method of classification of railway sections and
directions of operational activity for the formation of a sys-
tem of estimation of capabilities and efficiency improvement
in management of distribution of the railway infrastructure
capacity is proposed in [23].

To solve the classification problem, many neural network
architecture classifiers were created. They are widely used at
present in various fields. Analysis of neural network methods
for solving the classification problem is presented in [25–29]
and clustering algorithms in data mining are given in [30].
The essential shortcomings of the classification methods are
as follows. First, in classification problems, as a rule, the
number of classes is predefined and the boundary costs of the
attributes for each particular class are determined. Second,
with an increase in the number of factors considered, the ini-
tial set of classification objects is divided into an increasing
number of classes with a low level of representation of objects
in each of them which naturally reduces the level of trust to
the study results.

At the same time, a more substantiated theoretically
approach is associated with the use of a multidimensional
discriminant analysis.

The task of the multidimensional discriminant analy-
sis in classifying objects in the simplest two-dimensional
special case consists in assigning each particular object,
v, to one of two sets, W₁ or W₂, based on the observation p
of the controlled parameters, x₁,x₂,...,xₚ. The standard
classification procedure consists in the following [31, 32]. It
is assumed that the vector of observations, X, has a normal
distribution with parameters (μ,Σ) if it belongs to the set
W₁ and has a normal distribution with (μ,Σ) parameters if
this vector belongs to the set W₂. Here, the vectors μ₁ and
μ₂ also set the mathematical expectations of the components
X under given assumptions, and the matrices Σ₁ and Σ₂ are
variance matrices, moreover Σ₁=Σ₂.

Next, the so-called discriminant function is introduced

\[ z = \alpha_1 x_1 + \alpha_2 x_2 + \ldots + \alpha_p x_p, \]  

(1)

The object W is attributed to W₁ if

\[ z > C, \]  

(2)

and is attributed to W₂ if otherwise (C is a certain constant).

In this case, parameters αᵢ, i=1,2,…,p, and C
are sought in the following way.

If observation \( X \in W₁ \), then \( z \) belongs to the normal dis-
tribution \( N(\zeta,\Sigma) \) and if, however \( X \in W₂ \), then \( z \) belongs to the distribution \( N(\zeta',\Sigma') \) where

\[ \zeta = \sum_{i=1}^{p} \alpha_i \mu_i, \quad \zeta' = \sum_{i=1}^{p} \alpha_i \mu_i', \quad \Sigma = \sum_{i=1}^{p} \alpha_i \alpha_i' \Sigma_i. \]

The set \( \alpha_i, i=1,2,…,p \) is chosen so that the distance
of Mahalanobis [32] between \( W₁ \) and \( W₂ \) calculated from the formula

\[ \Delta^2 = \frac{(\zeta - \zeta')^2}{\sigma^2} \]

was maximal. It was shown in [33] that the sought set is de-
determined by solution of the system of linear equations.

\[ \alpha_1 \sigma_{11} + \alpha_2 \sigma_{12} + \ldots + \alpha_p \sigma_{1p} = \mu_1 - \mu_p, \]

\[ \alpha_1 \sigma_{21} + \alpha_2 \sigma_{22} + \ldots + \alpha_p \sigma_{2p} = \mu_1 - \mu_p, \]

\[ \ldots \ldots \ldots \ldots \ldots \ldots \]

\[ \alpha_1 \sigma_{pl} + \alpha_2 \sigma_{p2} + \ldots + \alpha_p \sigma_{pp} = \mu_1 - \mu_p. \]

(3)

and the constant C is calculated by formula

\[ C = \frac{1}{2} (\zeta_1 + \zeta_1'). \]

(4)

Next, the following are entered:

\[ P\left(H₁/X \in W₂\right) \]

is the probability that according to the results of calcula-
tions using formulas (1), (2), a hypothesis \( H₁ \) is accepted
about belonging of \( X \) to the set \( W₁ \), when in fact the object
belongs to \( W₂ \).

\[ P\left(H₂/X \in W₁\right) \]

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tions using formulas (1), (2), hypothesis \( H₂ \) is accepted
about belonging of \( X \) to the set \( W₂ \) when in fact the object
belongs to \( W₁ \).

The choice of \( C \) in accordance with (4) provides the
minimum cost of the total probability of mix-up.

The difficulties in implementing the standard technology
described herein are determined by the following circumstanc-
es. The practically insufficient number of observations leads to
unpredictable errors in sample estimates of the mean costs and
variances of controlled parameters that may be unpredictably
large. In addition, the very hypothesis about normality of the
random costs of these parameters cannot be reasonably accept-
ed or rejected. Finally, the use of hyperplanes (1) as discrimi-
nating functions leads to errors in the classification of objects.

The best results are ensured by the use of cluster analysis.

Cluster analysis occupies one of the central places among
the data analysis methods and is a collection of methods and
algorithms intended to find a certain partition of the
investigated set of objects into subsets of objects similar to
each other. At the same time, the following requirements are
usually presented to the results of clustering:
Control processes

- each cluster must contain objects with close of properties or attributes;
- the set of all clusters must be exhaustive, that is contain all objects of the set under study;
- no object from their set must not belong simultaneously to different clusters.

To solve the problem of clustering, many methods have been developed, the one-type concept of construction of which is displayed in the following way [34].

Let there be some set of objects that should be distributed among \( m \) clusters. At the same time, each object is characterized by a set of parameters \( F = \{ F_1, F_2, \ldots, F_n \} \) with their numerical costs for each object have been measured. Then, in the \( I \)-dimensional space of parameters, a point will correspond to each object and if a certain metric is given, then for each pair \( (j_i, j_j) \) of objects the distance between them can be calculated, for example, by formula

\[
r_{j_i,j_j} = \sqrt{\sum_{k=1}^{n} (F_{kj_i} - F_{kj_j})^2}, \quad p \geq 1.
\]

In many cases, coordinates of the objects are not entered, and immediately the matrix \( R = \{ r_{j_i,j_j} \} \) of distances is set. At the same time, the problem of clustering is formulated in the following way. Enter the indicator

\[
x_{ij} = \begin{cases} 1, & \text{if the } j \text{-th object was placed to the } i \text{-th cluster,} \\ 0, & \text{if otherwise.} \end{cases}
\]

Let the number of clusters, \( m \), be given. Then the formal statement of the problem of clustering takes the form: to find a set \( X = \{ x_{ij} \} \) by maximizing

\[
L(X) = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij} \cdot r_{j_i,j_j} - \sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij} \cdot x_{ij} \cdot r_{j_i,j_j}}{\sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij} \cdot x_{ij}}.
\]

and satisfying the constraints

\[
\sum_{j=1}^{n} x_{ij} = 1, \quad j = 1, 2, \ldots, n, \quad (6)
\]

\[
\sum_{i=1}^{m} x_{ij} \geq 1, \quad i = 1, 2, \ldots, m. \quad (7)
\]

The meaning of the optimized criterion is understandable. The numerator (5) has the mean distance between the clusters; it is desirable to maximize it. The denominator (5) represents the mean distance between the objects of the most noncompact, “loose” cluster; it is desirable to minimize it. Constraints (6), (7) determine allowable distribution of the objects among clusters. The resulting problem is a fractional-quadratic Boolean problem of mathematical programming. Exact solution of this problem is possible by exhaustive search which is not realistic in the problems of practical dimensionality. In connection with this, to solve the problem, a number of approximate heuristic algorithms were developed which are used to ensure rapid and qualitative division of objects among clusters. Thus, the problem of clusterization in the formulation (5)–(7) does not cause fundamental difficulties.

Solving the clustering problems at a microlevel [35–38] and forming clusters at a macrolevel [39–41] of the enterprise contributes to the growth of efficiency of the supply processes.

In particular, this method is used in work [35] for analysis of Ukrainian industry sectors by sources of innovation financing, in the study of development of metallurgical enterprises on the basis of production, financial-economic and logistic indicators [36]. Efficiency of clustering transport and logistics enterprises was substantiated in [37]. In the above-mentioned works, clustering was carried out at a micro-level of enterprises.

Clustering of urban areas taking into account logistics characteristics was carried out in [38]. The results of analysis of regional motor transport network by the hierarchical clustering method are given in [39]. An analysis of preconditions for formation of near-border transport and logistics clusters for improvement of international rail freight traffic are presented in [40].

Comparison at the macrolevel on the basis of statistical data of international service trade was made in [41]. The paper estimates competitive position of Turkey among the 148 member states of the World Trade Organization based on cluster analysis.

An important disadvantage of the object grouping technologies using cluster analysis is the lack of informativeness of the results obtained in clustering. The belonging of an object to a cluster is weakly related to the real costs of its characteristics. They can vary significantly depending on whether this object is located in the center of the cluster or near its boundaries.

Another approach to classification of objects is significantly more informative. It provides search for an analytical relationship connecting the numerical costs of the sets of factors that determine main characteristics of the object with the cost of the resulting system indicator chosen in some way. For many reasons, such a correlation, usually called the response function, is conveniently chosen in the form of so-called Kolmogorov-Gabor polynomial [42]:

\[
y(X) = a_0 + a_1 x_1 + a_2 x_2 + \ldots + a_n x_n + a_{12} x_1 x_2 + \ldots + a_{n-1,n} x_{n-1} x_n,
\]

where \( x_j \) is cost of the \( j \)-th factor, \( j = 1, 2, \ldots, n \); \( a_j \) is weight factor, importance of the \( j \)-th indicator, \( j = 1, 2, \ldots, n \). \( y \) is the resultant indicator.

Here, the maximum accountable degree of interaction of the factors is equal to two.

If the results of \( N \) experiments are used to estimate the polynomial (8) parameters, then the best vector in the sense of least squares is \( A^T = (a_0, a_1, a_2, \ldots, a_n, a_{12}, \ldots, a_{n-1,n}) \) vector determined by formula

\[
A = (H^T H)^{-1} H^T Y, \quad (9)
\]

\[
H = \begin{bmatrix}
1 & x_{11} & x_{12} & \ldots & x_{1n} & x_{11} x_{12} & \ldots & x_{11} x_{1n} \\
1 & x_{21} & x_{22} & \ldots & x_{2n} & x_{21} x_{22} & \ldots & x_{21} x_{2n} \\
\vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\
1 & x_{n1} & x_{n2} & \ldots & x_{nn} & x_{n1} x_{n2} & \ldots & x_{n1} x_{nn}
\end{bmatrix},
\]
Here \( x_i \) is the cost of the \( i \)-th factor in the \( i \)-th experiment; \( y_i \) is the cost of the resulting indicator in the \( i \)-th experiment.

The above conventional scheme is realized when there is a sufficient amount of initial experimental data. However, organization and conduction of an appropriate number of experiments are not feasible in many practical situations. Theoretical problems of an adequate estimation of parameters of the regression equation (8) require studies and solutions.

Such a wide range of studies shows the interest of scientists in the problems of transport and logistics systems and complexity of the problems. However, for a more accurate and objective reflection of processes, development of an integrated approach to presentation, analysis and evaluation of efficiency of transport and logistics systems requires further development.

For efficient management of international transport-logistics delivery systems, systems analysis shall be applied based on integration of various methods. It is necessary to combine statistical analysis of data on transport and freight flows to determine factor influence, apply modern methods of logistic analysis, etc. Improvement of the methods of solving classification problems will ensure obtaining of a more accurate solution of multifactor problems occurring in activities of transport and logistics companies and will enable formulation of appropriate strategies during planning and control of goods supply.

3. The aim and objectives of the study

This study objective was to formulate a method for classification of objects and processes in transport and logistics systems on the basis of multifactor analysis.

To achieve this objective, the following tasks had to be solved:
- to formalize description of the classification problem in solving transport and logistics problems and the theory of organization of cargo traffic on the basis of multifactor analysis;
- to propose a model and an algorithm for solving problems of classification of transport and logistics processes on the basis of factor and logistic analysis;
- to solve the problem of classification of Ukraine’s partner countries in terms of international trade turnover in various directions.

4. Formation of the method and the model for solving multifactor problems of classification of the transport and logistics processes

Formalized description of the classification problem for the transport and logistics systems on the basis of multifactor analysis was conducted in several stages. At the first stage, a regression model of the system was formed based on the systemic hierarchy analysis method. At the second stage, an analytical indicator is formed that characterizes influence of factors on the objects under study. At the third stage, ideas of the method of logistic ABC analysis are used for classification of transport and logistics processes and objects by the degree of manifestation of the factor influence. Let us make a formal description of these stages.

4.1. Formal description of the problem using a regression model

In the conditions of a small sample of initial data, it is difficult to realize the standard technology of the method of least squares leading to (9).

Alternative technologies for assessing importance of concrete indicators (characteristics) of the objects are based on processing of the results of expert judgements. When doing this, experts, along with independent estimation of relative importance of partial indicators rank them after which the sum of ranks determines final estimate of importance of each indicator. The obtained weight coefficients are used further for estimation of resultant indicators of the objects.

It is worth paying attention to the general design shortcoming of the conventional methods which is related to the insufficient adequacy of the procedure for calculating weight coefficients. Essentially, the weight coefficient calculated according to the above scheme is uniquely determined only by the place taken by a corresponding indicator in the table of ranks. However, actual importance of the two indicators that occupy adjacent positions in this table may differ much more significantly than is determined by their position. This shortcoming is of a general nature. In a similar situation, when direct estimation of weights of the parameters of the compared objects is difficult and the use of solely ranking can lead to an inaccurate choice. Recently, the method based on the paired preferences given some parameters over others is finding an ever-growing application. Expert estimation of such preferences is certainly a simpler task than the task of direct estimation of importance of parameters, and it is decided by experts much more confidently. The method proposed and substantiated in [43] was called the hierarchy analysis method and is implemented as follows [44–47].

Let each object of the set be characterized by \( n \) parameters. At the first stage, a matrix \( A \) of pairwise comparisons of significance (weight) of parameters is formed:

\[
A = \begin{pmatrix}
1 & a_{21} & \cdots & a_{n1} \\
a_{21} & 1 & \cdots & a_{n2} \\
\vdots & \vdots & \ddots & \vdots \\
a_{n1} & a_{n2} & \cdots & 1
\end{pmatrix},
\]

where \( a_{ij} \) is the number determining the preference level of the \( i \)-parameter over the \( j \)-parameter,

\[ a_{ii} = 1, \quad a_{ij} = (a_{ij})^{-1}, \quad i = 1,2,\ldots,n; \quad j = 1,2,\ldots,n. \]

Further, the eigen cost problem is solved for this matrix. In this case, the characteristic equation is formed

\[
\det\begin{pmatrix}
1-\lambda & a_{12} & \cdots & a_{1n} \\
a_{21} & 1-\lambda & \cdots & a_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
a_{n1} & a_{n2} & \cdots & 1-\lambda
\end{pmatrix} = 0.
\]

Its solution gives a set \( \lambda_1, \lambda_2,\ldots,\lambda_n \) of eigen quantities of the matrix \( A \). After this, the normalized (that is, one for
which the sum of components is equal to one) eigenvector $W$ of this matrix corresponding to the maximum eigen quantity $\lambda_{\text{max}} = \max(\lambda_1, \lambda_2, ..., \lambda_n)$ is found. The matrix $A$ is positive in its construction. As is known, the maximal eigen cost and the corresponding eigenvector are positive as well for such matrices. Let an eigen vector $W = (w_1, w_2, ..., w_n)$ be obtained as a result of solution. This vector components have meaning of the weight coefficients which characterize the relative importance of the object parameters. Let now the meaning of the weight coefficients which characterize the obtained as a result of solution. This vector components have for such matrices. Let an eigen vector $W = (w_1, w_2, ..., w_n)$ be determined by formula

$$V_k = \sum_{j=1}^{n} W_j F_{kj}, \quad k = 1, 2, ..., m. \quad (10)$$

The correlation connecting the maximal eigenvector of the matrix $A$ with a set of weight coefficients $W = (w_i)$ can be easily obtained if the matrix $A$ is consistent, that is,

$$a_{ij} = a_{ji}, \quad i = 1, 2, ..., n, \quad j = 1, 2, ..., n. \quad (11)$$

Sum up the left and right members of this equality by $j$.

$$\sum_{j=1}^{n} a_{ij} = \sum_{j=1}^{n} a_{ji}, \quad i = 1, n, \quad k = 1, n, \quad \sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij} = \sum_{i=1}^{n} \sum_{j=1}^{n} a_{ji}, \quad i = 1, n, \quad \sum_{i=1}^{n} a_{ij} = \sum_{j=1}^{n} a_{ji}, \quad i = 1, n, \quad \sum_{i=1}^{n} a_{ij} = \sum_{j=1}^{n} a_{ji}, \quad i = 1, n. \quad (12)$$

The matrix analogue of this correlation takes the form:

$$\frac{1}{n} AA = A. \quad (12)$$

Suppose that the weight coefficients $w_1, w_2, ..., w_n$ defining significance (importance, value) of the parameters are known. Then it is expedient to estimate significance of the $i$-th parameter in comparison with the $j$-th parameter by formula

$$a_{ij} = \frac{w_i}{w_j}, \quad i, j = 1, n. \quad (13)$$

Naturally, in this case,

$$\sum_{j=1}^{n} a_{ij} = 1, \quad i = 1, n, \quad \sum_{i=1}^{n} a_{ij} = n, \quad i = 1, n, \quad \sum_{i=1}^{n} a_{ij} = nw_i, \quad i = 1, n. \quad (14)$$

and, consequently,

$$\sum_{j=1}^{n} a_{ij} = \frac{1}{w_j} \sum_{i=1}^{n} a_{ij} = n, \quad i = 1, n, \quad \sum_{i=1}^{n} a_{ij} = n. \quad (14)$$

which corresponds to the equation $Aw = mw$.

It follows that for an reverse-symmetric positive consistent matrix, $A$, there is an eigen cost equal to $\frac{1}{n}$ and a positive, corresponding to this number eigenvector, $w$, with its components being weights of the elements. Thus, the resulting correlation establishes a connection between the matrix of pairwise comparison of parameter significance and the set of weight coefficients. Thus, if a matrix $A$ is given, then an unknown vector $w$ can be obtained by calculating this matrix eigenvector corresponding to an eigen quantity equal to $n$. At the same time, this vector $w$ can be obtained in a simpler way [48].

In accordance with (13), the matrix $A$ takes the form

$$A = \begin{pmatrix}
\frac{w_1}{w_1} & \frac{w_1}{w_2} & \frac{w_1}{w_3} \\
\frac{w_2}{w_1} & \frac{w_2}{w_2} & \frac{w_2}{w_3} \\
\frac{w_3}{w_1} & \frac{w_3}{w_2} & \frac{w_3}{w_3}
\end{pmatrix}.$$

Calculate the sums of the elements for each of the rows of the matrix $A$. For an arbitrary $i$-th line, the following is obtained:

$$\sum_{j=1}^{n} a_{ij} = \sum_{j=1}^{n} \frac{w_i}{w_j} = \sum_{j=1}^{n} \frac{1}{w_j} = Cw_i, \quad i = 1, n. \quad (14)$$

It follows from (14) that the eigenvector $w$ can be calculated to a constant directly from the elements of the matrix $A$. Define the constant $C$, proceeding from the natural requirement to normalization of the vector, $w$, in accordance with which the following condition shall be met:
\[ \sum_{j=1}^{n} a_{ij} = \sum_{i=1}^{n} c_{ai} = C \sum_{i=1}^{n} w_{i} = C, \]

(15)

It is clear that correlation (16) will allow us to make an accurate estimate of the weights of the parameters being compared only if the matrix \( A \) is consistent. However, in practice, a matrix \( A \) containing the results of pairwise comparisons of significance of the signs formed by experts is definitely not consistent. Therefore, the vector determined in accordance with (16) estimates the weight coefficients with an error the greater the more the real matrix \( A \) differs from the consistent matrix. The resulting problem can be solved in one of two ways. First, it is clear that the required transitive matrix of pairwise comparisons can be calculated if a set of results of comparison of importance of any indicator with respect to all the others is known. Suppose, for example, that a row \( \{a_{i}\} \) is given. Because

\[ a_{ij} = \frac{w_{i}}{w_{j}}, \]

then

\[ a_{ij} = \frac{w_{i}}{w_{j}} / \frac{w_{i}}{w_{j}} = \frac{w_{i}w_{j}}{w_{i}} = a_{ij}. \]

Thus, the \( i \)-th element of the \( j \)-th row of the matrix \( A \) can be reconstructed through the elements of the \( k \)-th row. Introduce

\[ \zeta_{s} = a_{0} - \bar{a}_{s}, \]

where \( a^{s} \) is the result of comparison of importance of indicators \( k \) and \( j \) obtained by the \( s \)-th expert, \( s = 1, m \).

Calculate

\[ \frac{\bar{a}_{s} + \zeta_{s}}{\bar{a}_{s} + \zeta_{s}} \left( \frac{\bar{a}_{s} + \zeta_{s}}{\bar{a}_{s} + \zeta_{s}} \right) = \frac{\bar{a}_{s} + \zeta_{s}}{\bar{a}_{s} + \zeta_{s}} \]

\[ = \frac{\bar{a}_{s} + \zeta_{s}}{\bar{a}_{s} + \zeta_{s}} \]

\[ = \frac{\bar{a}_{s} + \zeta_{s}}{\bar{a}_{s} + \zeta_{s}} \]

\[ = \frac{\bar{a}_{s} + \zeta_{s}}{\bar{a}_{s} + \zeta_{s}} \]

The approximate equality obtained follows from

\[ M \left[ \frac{\bar{a}_{s} + \zeta_{s}}{\bar{a}_{s} + \zeta_{s}} \right] = \bar{a}_{s} \]

Thus, it turns out that uncertainty in estimation of the calculated element \( a_{ij} \) of the matrix \( A \) is determined by uncertainty of \( a_{ij} \) and \( a_{ij} \) estimates. Let the random deviations \( \zeta_{s} \) and \( \zeta_{s} \) of these estimates from the corresponding mean costs be distributed normally with a zero average and variances \( \sigma_{s}^{2} \) and \( \sigma_{s}^{2} \), respectively. Then, as is known, density of distribution of a random quantity

\[ Z = \frac{\zeta_{s}}{\zeta_{s}} \]

is determined by the correlation
Control processes

\[ f(z) = \frac{\sigma_i}{\sigma_j} \left( \frac{\sigma_j}{\sigma_i} \right)^2 \]  

(the Cauchy distribution law).

For a random quantity distributed in accordance with the Cauchy law, it is impossible to determine estimates of the mathematical expectation and variance because of divergence of the integral

\[ \int \frac{|z|^{\alpha}}{\pi} \left( \frac{\sigma_j}{\sigma_i} \right)^2 \, dz \]  

for any \( \alpha \geq 1 \).

A compact representation of the system of equations (21) is obtained using matrix relations.

Introduce matrices

\[
A_i = \begin{bmatrix}
\frac{2(1 + \lambda_{ii})}{n} & \frac{\lambda_{ii}}{n} & \cdots & \frac{\lambda_{nn}}{n} \\
\frac{\lambda_{ii}}{n} & \frac{2(1 + \lambda_{ii})}{n} & \cdots & \frac{\lambda_{nn}}{n} \\
\vdots & \vdots & \ddots & \vdots \\
\frac{\lambda_{nn}}{n} & \frac{\lambda_{nn}}{n} & \cdots & \frac{2(1 + \lambda_{nn})}{n}
\end{bmatrix}
\]

\[
B = \begin{bmatrix}
\frac{\lambda_{ii}}{n} & 0 & 0 & 0 \\
0 & \frac{\lambda_{ii}}{n} & 0 & 0 \\
0 & 0 & \ddots & 0 \\
0 & 0 & 0 & \frac{\lambda_{nn}}{n}
\end{bmatrix}
\]

\[
A_n = \begin{bmatrix}
\frac{2(1 + \lambda_{11})}{n} & \frac{\lambda_{11}}{n} & \cdots & \frac{\lambda_{1n}}{n} \\
\frac{\lambda_{11}}{n} & \frac{2(1 + \lambda_{11})}{n} & \cdots & \frac{\lambda_{1n}}{n} \\
\vdots & \vdots & \ddots & \vdots \\
\frac{\lambda_{nn}}{n} & \frac{\lambda_{nn}}{n} & \cdots & \frac{2(1 + \lambda_{nn})}{n}
\end{bmatrix}
\]

Rewrite equations of the system (19) in a more convenient form:

\[
2(1 + \frac{\lambda_{ii}}{n}) x_{i1} + \frac{\lambda_{ii}}{n} \left( \sum_{j=1}^{n} x_{ij} + \sum_{j=1}^{n} x_{ji} \right) = 2a_{ii} + \lambda_{ii},
\]

\[
2(1 + \frac{\lambda_{ij}}{n}) x_{ij} + \frac{\lambda_{ij}}{n} \left( \sum_{k=1}^{n} x_{ik} + \sum_{k=1}^{n} x_{ki} \right) = 2a_{ij} + \lambda_{ij},
\]

\[
2(1 + \frac{\lambda_{nn}}{n}) x_{nn} + \frac{\lambda_{nn}}{n} \left( \sum_{j=1}^{n} x_{nj} + \sum_{j=1}^{n} x_{jn} \right) = 2a_{nn} + \lambda_{nn}.
\]

For a random quantity distributed in accordance with the Cauchy law, it is impossible to determine estimates of the mathematical expectation and variance because of divergence of the integral.

In this connection, implementation of the described variant of reconstruction of the matrix of pairwise comparisons can lead to gross errors in calculating coefficients of the regression equation and obtaining of an inadequate study result in general.

The second approach to solving the problem consists in finding the consistent matrix, \( X \), minimally in the sense of least squares differing from the given matrix, \( A \).

Let

\[ A = (a_{ij}), \quad i = \overline{1,n}, j = \overline{1,n} \]  

is the initial matrix of pairwise comparisons.

\[ X = (x_{ij}), \quad i = \overline{1,n}, j = \overline{1,n} \]  

is the sought consistent matrix of pairwise comparisons.

Formally, the problem can be formulated as follows: find a matrix \( X \) that minimizes

\[ F(X) = \sum_{i=1}^{n} \sum_{j=1}^{n} \left( x_{ij} - a_{ij} \right)^2 \]

and satisfies constraints

\[ \frac{1}{n} \sum_{i=1}^{n} x_{ii} = x_{ii}, \quad i = \overline{1,n}, j = \overline{1,n} \]

Solve this problem by the method of undetermined Lagrange multipliers. Form the Lagrange function:

\[ \Phi(x, \lambda) = \sum_{i=1}^{n} \sum_{j=1}^{n} (x_{ij} - a_{ij})^2 + \sum_{i=1}^{n} \sum_{j=1}^{n} \lambda_{ij} \left( \frac{1}{n} \sum_{i=1}^{n} x_{ii} - x_{ii} \right) \]  

(18)

Take partial derivatives of the problem variables from (18) and equate them to zero to obtain a system of equations

\[
\frac{\partial \Phi(x, \lambda)}{\partial x_{ij}} = 2(x_{ij} - a_{ij}) + \lambda_{ij} \left( \frac{1}{n} \sum_{i=1}^{n} x_{ii} + \sum_{j=1}^{n} x_{ij} - 1 \right) = 0, \quad i = \overline{1,n}, j = \overline{1,n},
\]

(19)

\[
\frac{\partial \Phi(x, \lambda)}{\partial \lambda_{ij}} = \frac{1}{n} \sum_{i=1}^{n} x_{ii} - x_{ij} = 0, \quad i = \overline{1,n}, j = \overline{1,n}.
\]

(20)

and vectors

\[ X_i = (x_{i1}, x_{i2}, \ldots, x_{in}), \quad X_n = (x_{1}, x_{2}, \ldots, x_{n}). \]
The following is obtained:

\[
P_i = \begin{pmatrix} 2a_{1i} + \lambda_{1i} \\ 2a_{2i} + \lambda_{2i} \\ \vdots \\ 2a_{ni} + \lambda_{ni} \end{pmatrix}, \quad \ldots, \quad P_n = \begin{pmatrix} 2a_{1ni} + \lambda_{1ni} \\ 2a_{2ni} + \lambda_{2ni} \\ \vdots \\ 2a_{nni} + \lambda_{nni} \end{pmatrix}.
\]

Write the system (21) using the notation introduced above:

\[
A_i X_i^T + B_i X_i^T + B_i X_i^T + \ldots + B_i X_i^T = P_i, \\
A_i X_i^T + A_i X_i^T + B_i X_i^T + \ldots + B_i X_i^T = P_i, \\
\quad \ldots \quad \ldots \quad \ldots \\
B_i X_i^T + B_i X_i^T + B_i X_i^T + \ldots + A_i X_i^T = P_n.
\]

The resulting system of linear algebraic equations can be solved numerically by any known method (Gauss, Jordan-Gauss, etc.). At the same time, the specific structure of the system (22) makes it possible to obtain a solution in an explicit form.

Rewrite equations of the system as follows:

\[
A_i X_i^T + B_i X_i^T + B_i X_i^T + \ldots + B_i X_i^T = P_i, \\
A_i X_i^T + B_i X_i^T + B_i X_i^T + \ldots + B_i X_i^T = P_i, \\
\quad \ldots \quad \ldots \quad \ldots \\
B_i X_i^T + B_i X_i^T + B_i X_i^T + \ldots + A_i X_i^T = P_n.
\]

or

\[
(A_i - B_i) X_i^T + B_i \sum_{j=1}^{n} X_j = P_i, \quad \ldots, \\
(A_i - B_i) X_i^T + B_i \sum_{j=1}^{n} X_j = P_n.
\]

Then

\[
B_i^{-1}(A_i - B_i) X_i^T - B_i^{-1}P_i = - \sum_{j=1}^{n} X_j^T, \quad \ldots, \\
B_i^{-1}(A_i - B_i) X_i^T - B_i^{-1}P_i = - \sum_{j=1}^{n} X_j^T.
\]

As a result,

\[
(B_i^{-1} A_i - I) X_i - B_i^{-1}P_i = \ldots = (B_i^{-1} A_i - I) X_i^T - B_i^{-1}P_i.
\]

Correlation (23) allows us to express \( X_j^T \), \( j = \frac{m+n}{2} \), through \( X_i^T \). The following is obtained:

\[
X_j^T = (B_j A_j - I)^{-1} \left[ (B_j A_j - I) X_i^T - B_j^{-1}P_i + B_j^{-1}P_j \right] = \\
= (B_j A_j - I)^{-1} (B_j A_j - I) X_i^T \\
\times X_i^T + (B_j A_j - I)^{-1} \left( B_j^{-1}P_j - B_j^{-1}P_i \right) = \\
= C_j X_i^T + D_{ij}, \quad j = \frac{m+n}{2}.
\]

Substituting (23) into the first equation of system (22), the following is obtained:

\[
\left( A_i + \sum_{j=2}^{n} C_{ij} \right) X_i^T + \sum_{j=2}^{n} D_{ij} = P_i,
\]

whence

\[
X_i^T = \left( A_i + \sum_{j=2}^{n} C_{ij} \right)^{-1} \left( P_i - \sum_{j=2}^{n} D_{ij} \right)
\]

and then, calculate \( X_1^T, \ldots, X_n^T \) using (24). Now a system of equations is obtained for finding values of the uncertain Lagrange multipliers which provides solution of the problem. Unfortunately, the resulting nonlinear system of equations can only be solved numerically. The complexity of solution of this problem increases rapidly (quadratically) with an increase in dimension of the problem. It should be mentioned that a simpler, iterative procedure for obtaining a consistent matrix was proposed in [49]. This procedure provides an approximate solution of the problem but accuracy of approximation improves at each step. The procedure is implemented as follows.

The fact is used that in the consistent matrix \( A \), for all \( i, j \) pairs, the following equalities are feasible

\[
a_{ij} = a_{ji}, \quad n a_{ij} = \sum_{l=1}^{n} a_{il} a_{lj},
\]

\[
a_{ij} = \frac{1}{n} \sum_{l=1}^{n} a_{il} a_{lj}, \quad i = \frac{m+n}{2}, \quad j = \frac{m+n}{2}, \quad k = \frac{m+n}{2}.
\]

This correlation, together with the set of equalities

\[
a_{ij} = \left( a_{ij} \right)^{-1}, \quad i = \frac{m+n}{2}, \quad j = \frac{m+n}{2},
\]

determines the consistent matrix. Since the real matrix of pairwise comparisons possesses only the property (27) but does not satisfy (26), the procedure of correction of the real matrix was proposed in [49]. This procedure provides an approximate solution of the problem but accuracy of approximation improves at each step. The procedure is implemented as follows.

The computational scheme is iterative. At each iteration, three steps are performed. Let \( l \) correction iterations be done resulting in obtaining of the matrix \( A_l \). At the next \( (l+1) \)-th iteration, the following calculations are performed.

Step 1. Calculate

\[
\frac{1}{n} A_i A_j = \hat{A}_{ij} = \left[ \hat{a}_{ij}^{(l)} \right].
\]

Step 2. Calculate

\[
\hat{a}_{ij}^{(l)} = \frac{\hat{a}_{ij}^{(l)}}{\left( \hat{a}_{ji}^{(l)} \right)^2}, \quad a_{ij}^{(l)} = \frac{a_{ij}^{(l)}}{\left( \hat{a}_{ji}^{(l)} \right)^2}.
\]
Control processes

It is clear that as a result of transformation of (29), the matrix $A_{ij}$ will satisfy (27) which in accordance with (28), ensures equality of diagonal elements of the matrix $A_{ij}$ to one. The matrix will be obtained in the next step. Since the original matrix possessed the property of (27), obviously all subsequent matrices $A_{ij}, A_{ij}..., A_{ij}$ with (28) taken into account, will have the same property.

**Step 3.**

Calculate

$$\eta_i = \max_{j} \left| x_{ij}^{(1)} - a_{ij}(x) \right|.$$ 

If the value obtained $\eta_i < \varepsilon$, where $\varepsilon$ is some sufficiently small preassigned number (for example, $\varepsilon = 10^{-5}$), then the procedure is considered completed. Otherwise, proceed to the next iteration.

Convergence of the correction procedure has been verified experimentally [50].

Thus, the proposed procedure for constructing the regression equation ensures restoration of an unknown relationship between a set of influencing factors and the selected resultant indicator under conditions of a small initial data sample based on the hierarchy analysis method.

Rapid determination of this dependence can be performed using the ABC classification. The ABC analysis is an effective management tool in logistics systems. It makes it possible to allocate certain groups of material resources depending on cost concentration. In general, the ABC analysis is a method by which the degree of distribution of a concrete characteristic (cost) between individual elements of a set is determined. The method of logistics ABC analysis is development of the Pareto principle in logistics problems. According to the Pareto principle (20/80 rule), a fifth (20 %) of the total number of objects usually give approximately 80 % of the result cost. Accordingly, contribution of the remaining 80 % of the objects yields only 20 %. In logistics, the ABC method offers a deeper division: into three parts [40]. This ensures rational allocation of resources and their effective management to achieve the goal.

According to the method of logistics ABC analysis, normalization and control of the objects under study consists in distribution of the set elements into three non-uniform subsets A, B, C based on a certain formal algorithm.

Let us apply the following algorithm for the classification based on the ABC analysis:

1) for each of the set elements of the objects of classification, take their value on the basis of the complex analytical indicators (indices) obtained in the second stage;
2) arrange the set elements in order of decreasing value;
3) determine share of each element of the set in the total amount of contribution;
4) build a cumulative curve: display the cumulative percentage in the number of objects on the abscissa axis and the cumulative percentage by contribution of each of the set elements to the overall estimate by the adopted cost indicator on the ordinate axis;
5) divide the set elements into classes corresponding to their shares in the total indicator.

Depending on the value of individual objects, the set is divided into three groups. The following classification is most typical [40]. The group “A” includes the most valuable objects which account for about 75–80 % of the total cost of resources, but they account for only 10–20 % of the total sum. Group “B” includes objects of an average cost with a share in the total cost about 10–15 % but it is 30–40 % in the quantitative terms. Group “C” contains the cheapest objects, 5–10 % of the total cost and 40–50 % of the total quantity.

However, the distribution is not necessarily made in three groups. The number of groups and limits can be chosen arbitrarily. Experts’ opinions and their experience can be used in this stage.

Proceeding from this classification, different levels of detail are laid down for each group of goods during planning and control.

Comparative characteristics of the three variants (empirical, differential and tangential) of the ABC analysis and analysis of the advantages and disadvantages of the used modifications are given in [51] by the example of drug consumption.

### 5. Classification of Ukraine’s partner countries based on a multi-factor analysis

Let us classify Ukraine’s partner countries by identifying the level of connections based on analysis of goods turnover in the areas of export and import of certain goods groups (GG) according to the Ukrainian Foreign Economic Activity Classifier (UF Eck) [52].

Initial data are formed based on the volumes and cost of goods of each group based on official customs statistics for 2016 [53]. Simulations were carried out in the Maple-7 environment using the Symbolic Computation package [54] and in the Microsoft EXCEL environment. For the classification based on the logistic ABC analysis, the advanced procedure of the graphical method [55] was used.

#### 5.1. Modeling on the basis of volumes and costs of international flows of individual goods groups

Let us consider the problem of classification of Ukraine’s trading partner countries in terms of volumes and cost of goods flows in “export” and “import” modes. Initial data were formed based on Ukrainian customs statistics for 2016 [53]. For the study, take individual groups of goods that can be transported in universal containers according to UFEAC. These are food and industrial goods of wide consumption, products of industrial-engineering use, agricultural products and household belongings, etc. Perishable stuffs, unpacked loose cargoes, explosives, flammable, caustic, stinking and toxic substances, etc. are unsuitable for transportation in universal containers. Goods that contaminate container walls and floor are excluded from the list as well. Also, goods that cannot be loaded into a container or unloaded without the use of cargo handling equipment are not included in the list of goods for container shipment.

For analysis, the weight and cost indicators for thirteen goods groups (GG) according to the UFEAC were taken. These are goods flows of goods groups under following UF-EAC codes: 43, 51, 52, 53, 57, 59, 60, 61, 62, 64, 65, 95 and 96 with the corresponding numbering of factors $i = 1...3$.

The aggregate weight and cost characteristics of the goods groups taken for analysis of the goods shipped in export and imports modes are presented in Table 1. For convenience of further use of this information, numerical of Ukraine’s partner countries was made by indicating the country ID in the set.
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<th>Weight, 1,000 t</th>
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The results of classification on the basis of logistics ABC analysis are shown in Fig. 1. Cumulative percentages by quantity represent the share of the total number of countries. The cumulated percentages by contribution represent the share by the estimated criterion of the cost of international goods flows moving in the “import” mode.

Class B includes 30% of the total number of countries and the share by the cost indicator is 7.5%. Class C includes 47% of countries with their cost contribution is only 0.6%.

Similarly, modeling was carried out for classification of countries by the criterion of the weight of goods flows in the “import” shipment mode as well as the criteria of cost and weight in the “export” shipment mode.

In the analysis of the main components of the data by weight of imported goods with a reliability of 0.9, five equations with a share of total variance were obtained, respectively, 53%, 14%, 10%, 8% and 7%.

The analysis of data by the cost of exported goods with a reliability of 0.81 has allowed us to obtain seven equations of the main components with a share of the total variance for each, 26%, 20%, 14%, 8%, 7%, 5% and 3%, respectively.

Based on the weight of exported goods, seven equations of the main components with reliability of 0.86 for the variance shares of 28%, 18%, 13%, 9%, 8%, 6%, and 5% were obtained, respectively.

At the second stage, based on hierarchy analysis method, analytical indicators (indices) were determined. They are presented in summary Tables 2, 3 and arranged in an order of their reduction. Countries and their identification numbers (ID) as well as the classification results are given in these tables.

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<td>B</td>
</tr>
<tr>
<td>2</td>
<td>Azerbaijan</td>
<td>0.00704</td>
<td>B</td>
<td>18</td>
<td>Kazakhstan</td>
<td>0.00726</td>
<td>B</td>
</tr>
<tr>
<td>8</td>
<td>Great Britain</td>
<td>0.00524</td>
<td>C</td>
<td>9</td>
<td>Vietnam</td>
<td>0.00697</td>
<td>B</td>
</tr>
<tr>
<td>31</td>
<td>Portugal</td>
<td>0.00454</td>
<td>C</td>
<td>13</td>
<td>Estonia</td>
<td>0.00348</td>
<td>B</td>
</tr>
<tr>
<td>35</td>
<td>USA</td>
<td>0.00412</td>
<td>C</td>
<td>31</td>
<td>Portugal</td>
<td>0.00234</td>
<td>C</td>
</tr>
<tr>
<td>11</td>
<td>Georgia</td>
<td>0.00405</td>
<td>C</td>
<td>2</td>
<td>Azerbaijan</td>
<td>0.00186</td>
<td>C</td>
</tr>
<tr>
<td>4</td>
<td>Afghanistan</td>
<td>0.00333</td>
<td>C</td>
<td>20</td>
<td>Kyrgyzstan</td>
<td>0.00160</td>
<td>C</td>
</tr>
<tr>
<td>20</td>
<td>Kyrgyzstan</td>
<td>0.00278</td>
<td>C</td>
<td>11</td>
<td>Georgia</td>
<td>0.00133</td>
<td>C</td>
</tr>
<tr>
<td>43</td>
<td>Switzerland</td>
<td>0.00122</td>
<td>C</td>
<td>34</td>
<td>Slovakia</td>
<td>0.00127</td>
<td>C</td>
</tr>
<tr>
<td>23</td>
<td>Latvia</td>
<td>0.00117</td>
<td>C</td>
<td>8</td>
<td>Great Britain</td>
<td>0.00122</td>
<td>C</td>
</tr>
<tr>
<td>34</td>
<td>Slovakia</td>
<td>0.00091</td>
<td>C</td>
<td>23</td>
<td>Latvia</td>
<td>0.00118</td>
<td>C</td>
</tr>
</tbody>
</table>
Control processes

The analysis presented in Tables 2, 3 shows that classification of a set of Ukraine's trading partners has resulted in three subsets (classes) which is well correlated with the classic ABC analysis.

5.2. Classification of the main Ukraine's partner countries in foreign trade based on an analysis of the specific value of the goods flows

Goods structure of goods flows between countries affects the indicator of specific value which is formed on the basis of data on the cost and weight of goods flows of individual goods groups. The flows between Ukraine and the trading partner countries, in particular, the modes of transportation (export, import), are also taken into account.

For the study, countries of the first twenty partners of Ukraine were selected based on the analysis of official statistics for 2016 based on the analysis of export and import flows. For selected countries, specific freight traffic costs were determined by analyzing weight and cost characteristics [53] for each of the flows of goods of individual groups according to UFEAC [52] to each of the selected countries in terms of export and import.

By the ratio of the goods cost to the goods weight for each of the traffic flows indicators were determined that characterize the value of goods in international goods turnover. Specific value indicators for each of twenty one groups of goods under the UFEAC (numbered as I, II,..., XXI) moving in the export and import modes according to the specified directions between Ukraine and the trading partner countries were calculated. These indicators were accepted as criteria for classification of countries.

An example of initial data for modeling of individual goods groups (I–V) and several partner countries are given in Table 4.

Factor analysis of Ukraine’s goods turnover in terms of exports of goods with major partner countries revealed with a reliability of 0.6 five equations of the main components that characterize influence of each of the factors: 19 % of the total variance are described by the first component, 13 % by the second component, 11 %, by the third component, 9 % by the fourth component and 8 % by the fifth component.

Table 4
Indicators of the specific cost of export and import goods flows

<table>
<thead>
<tr>
<th>Country</th>
<th>Movement direction</th>
<th>ID</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>...</th>
<th>XXI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Russia</td>
<td>export</td>
<td>1</td>
<td>0.624</td>
<td>0.352</td>
<td>1.115</td>
<td>0.890</td>
<td>0.031</td>
<td>...</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>import</td>
<td>1</td>
<td>0.235</td>
<td>0.607</td>
<td>0.404</td>
<td>1.552</td>
<td>0.122</td>
<td>...</td>
<td>0.830</td>
</tr>
<tr>
<td>Poland</td>
<td>export</td>
<td>3</td>
<td>1.606</td>
<td>0.156</td>
<td>0.741</td>
<td>0.277</td>
<td>0.047</td>
<td>...</td>
<td>1.402</td>
</tr>
<tr>
<td></td>
<td>import</td>
<td>5</td>
<td>0.811</td>
<td>0.915</td>
<td>1.113</td>
<td>1.922</td>
<td>0.157</td>
<td>...</td>
<td>0</td>
</tr>
<tr>
<td>Turkey</td>
<td>export</td>
<td>4</td>
<td>1.491</td>
<td>0.370</td>
<td>1.085</td>
<td>0.140</td>
<td>0.103</td>
<td>...</td>
<td>1.075</td>
</tr>
<tr>
<td></td>
<td>import</td>
<td>9</td>
<td>6.395</td>
<td>0.971</td>
<td>0</td>
<td>1.699</td>
<td>0.102</td>
<td>...</td>
<td>0</td>
</tr>
<tr>
<td>Italy</td>
<td>export</td>
<td>5</td>
<td>0</td>
<td>0.558</td>
<td>0</td>
<td>0</td>
<td>0.039</td>
<td>...</td>
<td>2.344</td>
</tr>
<tr>
<td></td>
<td>import</td>
<td>8</td>
<td>0</td>
<td>1.708</td>
<td>4.079</td>
<td>1.275</td>
<td>0</td>
<td>...</td>
<td>0</td>
</tr>
<tr>
<td>India</td>
<td>export</td>
<td>6</td>
<td>0</td>
<td>0.297</td>
<td>0.765</td>
<td>0</td>
<td>0</td>
<td>...</td>
<td>2.329</td>
</tr>
<tr>
<td></td>
<td>import</td>
<td>18</td>
<td>0</td>
<td>0.949</td>
<td>2.804</td>
<td>4.745</td>
<td>0.597</td>
<td>...</td>
<td>0</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Georgia</td>
<td>export</td>
<td>20</td>
<td>1.395</td>
<td>0.535</td>
<td>0</td>
<td>0.91</td>
<td>0.13</td>
<td>...</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>import</td>
<td>20</td>
<td>0</td>
<td>2.941</td>
<td>0</td>
<td>0.948</td>
<td>0.178</td>
<td>...</td>
<td>0</td>
</tr>
</tbody>
</table>
The factor analysis of Ukraine’s goods turnover in terms of import of goods with major partner countries revealed with a reliability of 0.6 six equations of the main components that characterize influence of each of the factors: 15% of the total variance are described by the first component, 12% by the second component, 10% by the third component, 9% by the fourth component, 8% by the fifth component and 7% by the sixth component.

The classification results are shown in Fig. 2, 3 and summarized in Table 5. Classification of international goods flows by the criterion of specific value of the goods flows moved in the "export" mode is shown in Fig. 5 and analogous data for the "import" mode are given in Fig. 3. Table 5 shows in a decreasing order the analytical indices determined at the second stage by the of hierarchy analysis method, countries with their identification numbers (ID) as well as the results of classification.

### Table 5

<table>
<thead>
<tr>
<th>ID</th>
<th>Country</th>
<th>Index</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Germany</td>
<td>0.386071</td>
<td>A</td>
</tr>
<tr>
<td>9</td>
<td>Hungary</td>
<td>0.340034</td>
<td>A</td>
</tr>
<tr>
<td>12</td>
<td>Belarus</td>
<td>0.330739</td>
<td>A</td>
</tr>
<tr>
<td>20</td>
<td>Georgia</td>
<td>0.319889</td>
<td>A</td>
</tr>
<tr>
<td>1</td>
<td>Russia</td>
<td>0.286304</td>
<td>A</td>
</tr>
<tr>
<td>6</td>
<td>India</td>
<td>0.282967</td>
<td>A</td>
</tr>
<tr>
<td>7</td>
<td>China</td>
<td>0.277638</td>
<td>A</td>
</tr>
<tr>
<td>18</td>
<td>Moldova</td>
<td>0.239381</td>
<td>A</td>
</tr>
<tr>
<td>3</td>
<td>Poland</td>
<td>0.199425</td>
<td>A</td>
</tr>
<tr>
<td>13</td>
<td>Runania</td>
<td>0.193231</td>
<td>A</td>
</tr>
<tr>
<td>16</td>
<td>Czech Republic</td>
<td>0.189345</td>
<td>A</td>
</tr>
<tr>
<td>2</td>
<td>Egypt</td>
<td>0.187958</td>
<td>A</td>
</tr>
<tr>
<td>11</td>
<td>Netherlands</td>
<td>0.179817</td>
<td>B</td>
</tr>
<tr>
<td>19</td>
<td>Slovakia</td>
<td>0.122348</td>
<td>B</td>
</tr>
<tr>
<td>5</td>
<td>Italy</td>
<td>0.117688</td>
<td>B</td>
</tr>
<tr>
<td>10</td>
<td>Spain</td>
<td>0.078537</td>
<td>B</td>
</tr>
<tr>
<td>4</td>
<td>Netherlands</td>
<td>0.068727</td>
<td>B</td>
</tr>
<tr>
<td>17</td>
<td>Israel</td>
<td>0.057136</td>
<td>B</td>
</tr>
<tr>
<td>15</td>
<td>Saudi Arabia</td>
<td>0.050304</td>
<td>B</td>
</tr>
<tr>
<td>14</td>
<td>Iran</td>
<td>0.030317</td>
<td>B</td>
</tr>
</tbody>
</table>

The classification results are summarized in Table 6. For each of the analyzed variants of initial data, indicators are presented that characterize classification of the set of Ukraine’s partner countries in the international goods turnover according to the corresponding criteria.

Analysis of data given in Table 5 shows that according to the criterion of specific value of goods flows, a set of studied countries can be divided into two classes. This is due to the fact that only twenty countries with the largest turnover were selected previously.

From the data given in Table 6, it appears that the boundaries of classes are dynamic and depend on the specific formulation of the problem and the criteria taken into consideration.

### Table 6

<table>
<thead>
<tr>
<th>ID</th>
<th>Country</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Russia</td>
<td>0.286304</td>
</tr>
<tr>
<td>9</td>
<td>China</td>
<td>0.277638</td>
</tr>
<tr>
<td>12</td>
<td>Italy</td>
<td>0.386071</td>
</tr>
<tr>
<td>20</td>
<td>Germany</td>
<td>0.340034</td>
</tr>
<tr>
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<td>Hungary</td>
<td>0.330739</td>
</tr>
<tr>
<td>6</td>
<td>Poland</td>
<td>0.286304</td>
</tr>
<tr>
<td>7</td>
<td>Spain</td>
<td>0.199425</td>
</tr>
<tr>
<td>13</td>
<td>Runania</td>
<td>0.193231</td>
</tr>
<tr>
<td>16</td>
<td>Czech Republic</td>
<td>0.189345</td>
</tr>
<tr>
<td>2</td>
<td>Egypt</td>
<td>0.187958</td>
</tr>
<tr>
<td>11</td>
<td>Slovakia</td>
<td>0.122348</td>
</tr>
<tr>
<td>5</td>
<td>Italy</td>
<td>0.117688</td>
</tr>
</tbody>
</table>
## Control processes

For a more accurate representation of the processes taking place in transport and logistics systems, it is necessary to use the results of statistical analysis of data on freight flows in a comprehensive manner, use current methods of logistic analysis.

This work proposes a method for classifying a set of objects and/or processes in transport and logistics systems on the basis of multifactor analysis and provides a formalized description. The method is implemented by combining regression analysis, system hierarchy analysis method and logistic ABC analysis.

A model and algorithm of solution of multifactor classification problems in solving problems of transport and logistics and theory of organization of cargo transportation were proposed. Simulation was carried out in two stages. At the first stage, a regression analysis model was developed based on the system hierarchy analysis method. At this stage, an analytical indicator characterizing influence of factors on objects under study was created. At the second stage, the ideas of the method of logistic ABC analysis for classification of transport and logistics processes and objects by the degree of manifestation of factor influence were used. Simulations were performed using symbolic composition package in the Maple-7 and the Microsoft Excel environments.

Classification of Ukraine’s partner countries by the indicators of international turnover of certain groups of goods which can be transported in universal containers in various directions according to the Ukrainian foreign economic activity classifier (UFEAC) have shown the following:

- classification of countries with the help of an advanced procedure of the graphical method of ABC analysis [55] has allowed us to divide the set of Ukraine’s partner countries in foreign trade into three classes;
- boundaries of the classes are dynamic and depend on the specific problem statement and the criteria taken into account.

When classifying countries by the criterion of cost of goods flow in the “import” mode, 23 % of the total number of countries whose share according to the cost indicator is 92 % were assigned to class A. 26 % of the total number of countries whose share according to the cost index is 7.2 % were assigned to class B. 51 % of the countries whose share according to the cost indicator is only 0.8 % were assigned to class C (Tables 2, 6). Class A includes the following countries: China, Turkey, Germany, Poland, Italy, Belgium, the Netherlands, Russia, Belarus, France, and India.

When classifying countries according to the criterion of weight of goods flows in the “import” mode, 32 % of the total number of countries with their share according to the cost indicator is 93 % were assigned to class A. Class B includes 19 % of the total number of the countries with their share according to the cost index is 8.6 %. Class C includes 49 % of the countries whose share according to the cost index is only 0.4 % (Tables 2, 6). Class A includes the following countries: China, Italy, Bangladesh, Poland, Turkey, Belarus, Russia, Germany, Moldova, Turkmenistan, Belgium, India, France, Australia, and the Netherlands.

When classifying countries according to the criterion of cost of goods flows in the “export” mode, 27 % of the total number of countries, the share according to the cost index is 89.9 % were assigned to class A, 23 % of the total number of countries with their share according to the cost indicator is 8.5 % were assigned to class B Class C includes 50 % of the countries with their according to the cost indicator is only 1.6 % (Table 3, 6). Class A includes the following countries: Russia, Poland, Germany, Romania, Italy, Kazakhstan, Denmark, Uzbekistan, Turkmenistan, Belgium, Belarus, Belgium, and Hungary.

In classification of countries according to the criterion of weight of goods flows in “export” mode, 25 % of the total number of countries with their share of the cost indicator is 90 % were assigned to class A. Class B includes 29.5 % of the total number of countries with their share according to the cost indicator is 13.4 %. Class C includes 46.5 % of the countries with their share according to the cost indicator is only 0.6 % (Tables 2, 6). Class A includes the following countries: Russia, Poland, Italy, Romania, Austria, China, Belgium, Germany, Denmark, Lithuania, and Belarus.

Since classification was carried out for a set of all partner countries, the classification results are in line with the classic ABC analysis.

Classification of countries according to the criterion of specific value of goods flows has allowed us to divide the set of countries under study into two classes. This is explained by the fact that only twenty countries with the largest goods turnover were selected previously.

When classifying countries according to the criterion of the specific value of goods flows in the mode of “export” 60 % of the total number of countries with their share of contribution is 82 % were assigned to class A. Class B includes

### Table 6

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Value, export</th>
<th>Value, import</th>
<th>Cost, export</th>
<th>Cost, import</th>
<th>Weight, export</th>
<th>Weight, import</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limit of classes A/B by quantity, %</td>
<td>60</td>
<td>65</td>
<td>27</td>
<td>23</td>
<td>25</td>
<td>32</td>
</tr>
<tr>
<td>Limit of classes A/B by contribution, %</td>
<td>82</td>
<td>81</td>
<td>89.9</td>
<td>92</td>
<td>90</td>
<td>93</td>
</tr>
<tr>
<td>Limit of classes B/C by quantity, %</td>
<td>–</td>
<td>–</td>
<td>50</td>
<td>49</td>
<td>54.5</td>
<td>51</td>
</tr>
<tr>
<td>Limit of classes B/C by contribution, %</td>
<td>–</td>
<td>–</td>
<td>98.4</td>
<td>99.2</td>
<td>99.4</td>
<td>99.6</td>
</tr>
<tr>
<td>Number of objects in Class A, %</td>
<td>60</td>
<td>65</td>
<td>27</td>
<td>23</td>
<td>25</td>
<td>32</td>
</tr>
<tr>
<td>Number of objects in Class B, %</td>
<td>40</td>
<td>35</td>
<td>23</td>
<td>26</td>
<td>29.5</td>
<td>19</td>
</tr>
<tr>
<td>Number of objects in Class C, %</td>
<td>–</td>
<td>–</td>
<td>50</td>
<td>51</td>
<td>46.5</td>
<td>49</td>
</tr>
<tr>
<td>Ponderability of objects in Class A, %</td>
<td>82</td>
<td>81</td>
<td>89.9</td>
<td>92</td>
<td>90</td>
<td>93</td>
</tr>
<tr>
<td>Ponderability of objects in Class B, %</td>
<td>18</td>
<td>19</td>
<td>8.5</td>
<td>7.2</td>
<td>13.4</td>
<td>8.6</td>
</tr>
<tr>
<td>Ponderability of objects in Class C, %</td>
<td>–</td>
<td>–</td>
<td>1.6</td>
<td>0.8</td>
<td>0.6</td>
<td>0.4</td>
</tr>
</tbody>
</table>
40% of the total number of countries with contribution share of 18% (Tables 5, 6).

In classification of countries according to the criterion of specific value of goods flows in the “import” mode, 65% of the total number of countries with their contribution share of 81% were assigned to class A. Class B includes 35% of the total number of countries with their contribution share of 19% (Tables 5, 6). Class A includes the following countries: Italy, France, Hungary, Germany, India, Czech Republic, China, Great Britain, Poland, Austria, USA, Japan, and Switzerland.

This study is the development of the ideas set forth in papers [7,8,13,56]. Using the hierarchy analysis method in an unifying model helps in structuring the problems of decision makers by building a hierarchy in accordance with the purpose, task and understanding of factors. Based on the use of statistical data, time series of dynamics are formed. Meaningful analysis of information makes it possible to create various sets of factors. This may be the characteristics by the goods groups, directions of the movement of goods flows, etc.

Application of the simplified hierarchy analysis method in the study facilitates formation of a versatility analytical indicator. A thorough statistical analysis adds objectivity to the estimates since it is based on actual data. However, processing of large statistical data bodies in preparation of initial data is a labor intensive procedure.

The use of the hierarchy analysis method in solving multifactor decision-making problems may involve experts in this process. This is a complicated procedure connected with formation of a group of experts, conduction of polls, analyzing questionnaires, and the like. However, when analyzing intricate problems, it can give more accurate estimates of the problem.

More generally, use of the ideas of the method of logistic ABC analysis enables distribution of objects of classification among various numbers of groups and their boundaries can be chosen arbitrarily. Experts’ opinions and experience may be useful at this stage.

The proposed classification method can be applied in transport, logistics, customs and brokerage enterprises, as it ensures planning and control of the goods supply, provide for varying degrees of detail and apply appropriate strategies.

Further development and improvement of the study is possible for using intelligent systems and algorithms in solving the problems of multifactor analysis of transport and logistics systems. In this case, the main goal may be development of a method of joint analysis of numerical characteristics of transport and logistics systems obtained over several years. It is clear that the problems arising from processing of a small sample of initial data seriously impede the possibility of using conventional probability-theoretic methods. A natural alternative may be the mathematical apparatus of the fuzzy [57] and inaccurate [58] mathematics using the methods proposed in [59, 60].

7. Conclusions

1. The method of classification of a set of objects and/or processes in the transport and logistics systems based on the multifactor analysis was proposed. The method was implemented by combining regression analysis, systems of hierarchy analysis method and the method of logistic ABC analysis. This allows one to form dynamic classes based on comprehensive assessment of factor effects depending on the specific problem statement and the criteria to be taken into account. The use of the proposed classification method in activities of transport and logistics companies will enable formation of appropriate strategies for planning and control of goods supply.

2. Combination of methods of statistical and regression analysis, the systems hierarchy analysis method and modern methods of logistic analysis has allowed us to form a unifying model of classification. A three-stage algorithm was proposed for solving multifactor classification problems in the field of transport and logistics and the theory of organization of cargo transportation. At the first stage, the regression method investigates the factor influence based on the chosen system of criteria. At the second stage, an analytical indicator characterizing degree of factor influence on the objects under investigation and based on the systemic hierarchy analysis method was formed. The use of the hierarchy analysis method makes it possible both to use factual data based on a thorough statistical analysis and involve experts in solving multriterial decision-making problems. The use of modern logistic analysis methods at the third stage enables substantiated division of classified objects in the transport and logistic systems into various numbers of dynamic classes. At this stage, it is also possible to involve experts in formation of boundaries between classes. The model was implemented using symbolic computation package in the Maple-7 and in the Microsoft Excel environments.

3. Classification of Ukraine’s trading partners according to the international turnover of certain groups of goods which can be transported in universal containers according to the Ukrainian foreign economic activity classifier (UFEAC) has been made. Through simulation, the set of partner countries in foreign trade was divided into three classes. The classification results are in good agreement with the classic ABC analysis. Classification of countries according to the criterion of specific value of goods flows has allowed us to divide the set of countries under study into two classes. This is explained by the fact that classification was carried out for a set of all partner countries in the first example and previous selection of twenty countries with the largest turnover was made in the second example.

Application of the proposed method of multifactor classification enables division of the classified objects, in general, among various numbers of groups. At the same time, boundaries of the classes are dynamic and depend on concrete formulation of the problem and the criteria taken into account.

References