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Article

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DEVELOPMENT OF AN ALGORITHM FOR EVALUATION OF A COMPREHENSIVE RISK MANAGEMENT INDICATOR IN FOOD SAFETY MANAGEMENT SYSTEMS

The object of research is risk management in food safety management systems. The subject of the study is individual indicators, criteria and a comprehensive indicator of risk management for food safety. One of the most problematic areas is the lack of a common methodology for food safety risk assessment for the development, implementation and operation of food safety management systems. This leads to the fact that it is impossible to properly assess the risk groups depending on the object of management:

– unintentional threats (HACCP concept – hazard analysis and critical control points);

– intentional threats (concepts VACCP – vulnerability analysis and critical control points, TACCP – threat analysis and critical control points). And evaluate the overall effectiveness of the food safety management system.

The study used methods of systems analysis and mathematical modeling as the main research method in all fields of knowledge. As well as a scientifically sound method of assessing the characteristics of complex systems used for decision-making in various fields of economic, managerial and social activities.

The proposed in the work algorithm allows to quantify the level of risk management in the food safety management system by such groups as unintentional and intentional threats, taking into account the general indicators of the criteria and their factors. The overall criterion for unintentional threats, which are identified using HACCP principles, is determined by three criteria: microbiological threats, chemical threats and control measures, which in turn include a number of factors. The general indicator of the criterion for intentional threats, which are identified using the principles of VACCP and TACCP, is also determined by three criteria: opportunities, motivation and control measures, which in turn have a separate number of factors.

The obtained algorithm allows to determine the levels of risk management and serve as an effective tool for obtaining objective information about the effectiveness of the implementation of the food safety management system. In contrast to existing methods of food safety risk assessment, which are based only on the management of unintentional threats, the proposed algorithm allows to take into account the impact of intentional threats – fraud and bioterrorism. And consider food safety risks comprehensively and develop options for improving management measures.

Keywords: *risk assessment algorithm, HACCP, VACCP, TACCP, safety criteria, safety factors, comprehensive indicator.*

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1. Introduction

The main purpose of legislative, regulatory bodies and food market operators is to ensure the food safety, taking into account the entire life cycle of food products.

In recent years, the ineffectiveness of existing risk management methodologies for food safety has become increasingly apparent. Existing methodologies and techniques of qualimetry, which are based on an integrated approach to risk assessment at the operational level, take into account only unintentional threats and HACCP principles (hazard analysis and critical control points).

Methods for assessing food safety risks for many facilities are not available or are in the process of being developed. The existing ones most often contain nonconformities and do not comply with international norms and requirements of standards, which does not allow unambiguous and complete interpretation of the results. Therefore, conducting research that allows to unify the methodology, to develop algorithms for risk management solutions in food safety management systems, taking into accrdance with international norms and requirements of standards should be considered relevant.

2. The object of research and its technological audit

The object of research is risk management in food safety management systems. The subject of the study is individual

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factors, criteria and a comprehensive indicator of risk management for food safety. One of the most problematic areas is the lack of a common methodology for assessing food safety risks for the development, implementation and operation of food safety management systems. This leads to the fact that it is impossible to properly assess risk groups depending on the object of management:

– unintentional threats (HACCP concept);
– intentional threats (concepts VACCP – vulnerability analysis and critical control points, TACCP – threat analysis and critical control points). And evaluate the overall effectiveness of the food safety management system.

3. The aim and objectives of research

The aim of research is to develope a scientifically sound and clear algorithm for evaluating a comprehensive risk management indicator in the development, implementation and operation of food safety management systems. And taking into account the methodology of unintentional threats prevention (HACCP principles), and the methodology of protection against intentional threats (principles of VACCP, TACCP).

To achieve this aim it is necessary to perform the following objectives:

1. To identify individual factors and criteria for assessing the risks of unintentional and intentional threats to food safety.
2. To substantiate and choose a mathematical apparatus that allows a comprehensive assessment of risk management in the development, implementation and operation of food safety management systems.

4. Research of existing solutions of the problem

Since 1997, international and regional organizations in the field of agriculture and food, as well as standardization have been publishing guidelines and recommendations for risk identification, assessment and management [1, 2], including:

– Codex Alimentarius Commission [3, 4];
– European Food Safety Authority [5, 6];
– World Organization for Agriculture and Food FAO [7, 8]. In particular, these organizations identify food safety risks taking into account the significance of the impact on consumer health and identify microbiological and chemical risks that can be identified using the HACCP concept [9]. International and regional professional organizations do not have established recommendations or guidelines for managing the risks of deliberate threats based on VACCP and TACCP principles.

Since 2014, the Global Food Safety Initiative (GFSI) has published a position on reducing the risk of harm through economically motivated food fraud. In [10], the GFSI Board decided to recommend that food fraud schemes include two stages of mitigation in recognized food safety management schemes and standards in two key elements:

1) require the company to assess the risks of fraud vulnerability;

2) have a risk management plan. However, no clear methodology and methods for identifying and managing risks to the prevention of food fraud have been identified, and food market operators have had to apply common approaches and methods borrowed from the HACCP concept.

The British Department of the Environment, Food and Agriculture (DEFRA) and the British Food Standards Agency (FSA), with the assistance of the British Standards Institution (BSI), developed PAS 96 [11]. This document is a guide to the application of the principles of TACCP and VACCP prevention of intentional harm and spoilage of food, including: extortion, intentional contamination (bioterrorism), cybercrime, espionage, economically motivated fraud, counterfeiting [11].

At present, all standards and certification schemes recognized by the GFSI are required to assess the risks of intentional harm and to develop management measures.

The author has developed a general concept of food safety risk management, which involves assessing the risks of intentional and unintentional threats [12].

The structural and schematic model of the concept is presented in Fig. 1.

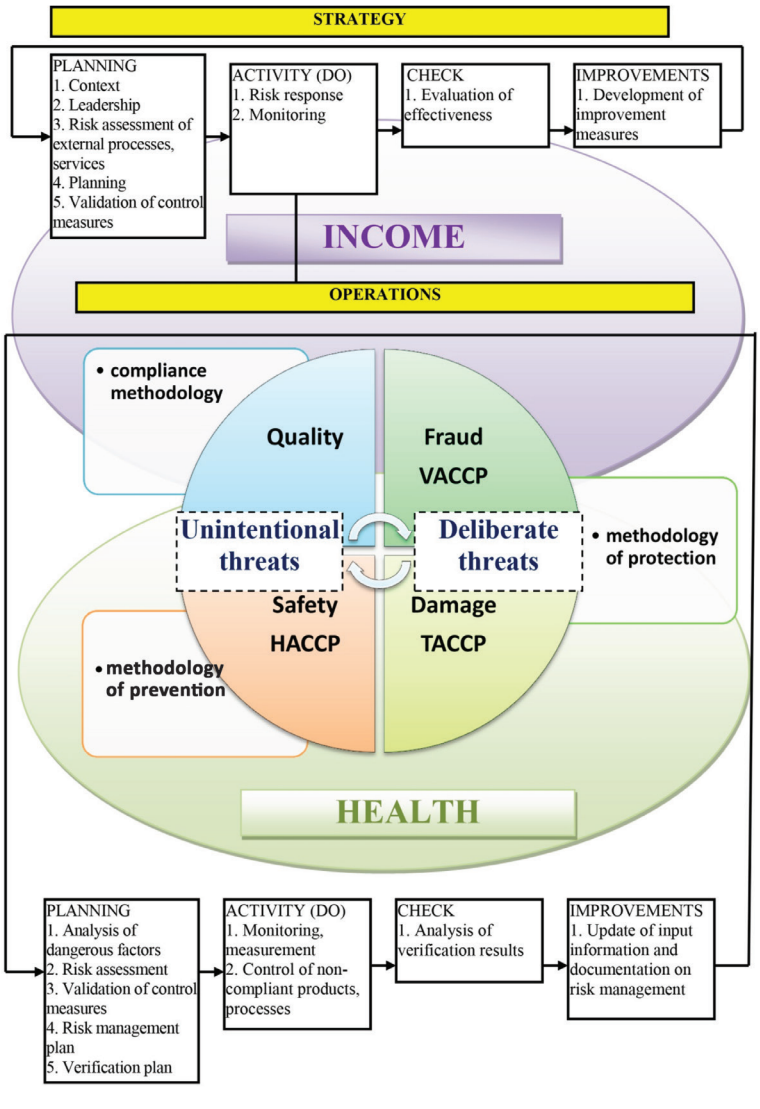

Fig. 1. Structural and schematic model of the risk management concept in food safety management systems

After the development of the concept, there was a need to identify factors and criteria for risk management, as well as the creation of a mathematical apparatus for such a solution that will allow a comprehensive assessment of risk management in food safety management systems.

5. Methods of research

Methods of systems analysis and mathematical modeling were used in research. These methods are used as the main method of assessing the characteristics of complex systems for decision-making in various areas of economic, managerial and social activities.

6. Research results

The description and structure of the risk management method in FSMS (food safety management systems) is formed as a system of criteria indicators, taking into account the objects of influence and individual factors that are part of a comprehensive risk management indicator for food safety.

A comprehensive, systematic analysis of indicators should be carried out taking into account the dynamics of changes in the quantitative characteristics of individual factors and indicators, expert assessments and scientific information (absolute deviation) and the vector of the objective function of risk management in FSMS. This approach will assess the risks of food market operators to prevent unintentional and intentional threats and their degree of management.

The dynamics of growth of the components of the system requires their rationing or scaling for the needs of a comprehensive assessment:

$$\begin{Bmatrix} \text{If } F_i \to \min, \text{ then } D = X_i - X_f \\ \text{If } F_i \to \max, \text{ then } D = X_f - X_i \end{Bmatrix}, \quad (1)$$

where F_i – target function of control by the food market operator of the i-th indicator of the criterion; X_i – value obtained before the implementation of FSMS (initial value); X_f – the value obtained after the implementation of FSMS (final value).

The normalization of the survey data is carried out in accordance with the maximum and minimum values of the sample data for each indicator separately. In addition, the method assumes the presence of a neutral level «0», and the general limits of the obtained indicator are in the range [0; 1]. The level «0» is the state of the system when the indicators do not change in a certain period. This approach allowed scaling the values according to the following distribution:

$$\Delta_i = \begin{Bmatrix} 0.5 + \dfrac{0.5 \cdot X_i}{\max_i \left(|\min_i|, |\max_i|\right)}, & \text{if } \Delta > 0 \\ 0.5, & \text{if } \Delta = 0 \\ 0.5 - \dfrac{0.5 \cdot X_i}{\max_i \left(|\min_i|, |\max_i|\right)}, & \text{if } \Delta < 0 \end{Bmatrix}, \quad (2)$$

where Δ_i – dynamics of change of the i-th indicator of system; $\max_i \left(|\min_i|, |\max_i|\right)$ – the maximum level in the range of values of the maximum and minimum change of the i-th indicator of the system.

Application (2) allows to determine the levels of the system by a comprehensive indicator of risk management FSMS. The ranking of the levels of the system is presented in Table 1.

Table 1

Ranking the levels of the risk management system

The level of the system state	Indicator value
Uncontrolled	0–0.3
Neutral («0»)	0.4–0.7
Controlled	0.8–1.0

The general evaluation of the each criterion indicators for determining a comprehensive indicator of food safety risk management was conducted by (3).

$$K_i = \frac{\sum_{i=1}^{n} \Delta_i}{n}, \quad (3)$$

where K_i – indicator of the criterion of individual components of the system; n – the total number of factors included in the indicator of the criterion.

Let's analyze the criteria of the components of the system, which are formed from general indicators and individual factors.

The first group of indicators allows to manage the risk in FSMS for unintentional threats that are identified using the principles of HACCP (HACCP risks). The criteria for the overall risk management indicator are microbiological threats, chemical control measures, which combine factors that characterize unintentional threats to food safety.

General indicators and individual factors of this group are presented in Table 2.

Table 2

General indicators and individual risk management factors of hazard analysis and critical control points (*RH*)

Criterion	Factors	Target function/absolute deviation
1	2	3
Microbiological – *RH*(*M*)	Category of raw materials	$RH(M)_1 \to \max$ $\Delta M_1^i - M_1^f$
	Finished product category	$RH(M)_2 \to \max$ $\Delta M_2^i - M_2^f$
	Pathogenicity of pathogens	$RH(M)_3 \to \min$ $\Delta M_3^i - M_3^f$
	Ensuring storage conditions – raw materials	$RH(M)_4 \to \max$ $\Delta M_4^i - M_4^f$
	Ensuring storage conditions – the finished product	$RH(M)_5 \to \max$ $\Delta M_5^i - M_5^f$
	Presence of limit limits, MPC (maximum permissible concentration), MPN (maximum permissible norm)	$RH(M)_6 \to \max$ $\Delta M_6^i - M_6^f$
	The state of sanitation – raw material	$RH(M)_7 \to \max$ $\Delta M_7^i - M_7^f$
	The state of sanitation – finished product	$RH(M)_8 \to \max$ $\Delta M_8^i - M_8^f$
	Probability of cross-contamination	$RH(M)_9 \to min$ $\Delta M_9^i - M_9^f$
	The presence of technological processes designed for regulation – the finished product	$RH(M)_{10} \to \max$ $\Delta M_{10}^i - M_{10}^f$
	Impact on the consumer health	$RH(M)_{11} \to \min$ $\Delta M_{11}^i - M_{11}^f$
	Information on cases of poisoning	$RH(M)_{12} \to \min$ $\Delta M_{12}^i - M_{12}^f$

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Continuation of Table 2

1	2	3
Chemical – $RH(C)$	Category of chemicals (Ch) – accidental ingestion – raw materials	$RH(C)_1 \to \min$ $\Delta C_1^i - C_1^f$
	Category of chemicals (Ch) – accidental ingestion – the finished product	$RH(C)_2 \to \min$ $\Delta C_2^i - C_2^f$
	Category of chemicals – have been entered under technological processes conditions	$RH(C)_3 \to \min$ $\Delta C_3^i - C_3^f$
	Residues of chemicals (pesticides, veterinary drugs, excipients) – raw materials	$RH(C)_4 \to \min$ $\Delta C_4^i - C_4^f$
	Food additives (flavorings, flavor enhancers, colors, etc.)	$RH(C)_5 \to \min$ $\Delta C_5^i - C_5^f$
	The presence of conditions for toxins accumulation	$RH(C)_6 \to \min$ $\Delta C_6^i - C_6^f$
	The allergens presence	$RH(C)_7 \to \min$ $\Delta C_7^i - C_7^f$
	Possibility of insertion chemicals from the environment	$RH(C)_8 \to \min$ $\Delta C_8^i - C_8^f$
	The presence of maximum residue limits, MPC, MPN	$RH(C)_9 \to \max$ $\Delta C_9^i - C_9^f$
	Probability of cross-contamination	$RH(C)_{10} \to \min$ $\Delta C_{10}^i - C_{10}^f$
	The presence of technological processes designed for regulation – the finished product	$RH(C)_{11} \to \max$ $\Delta C_{11}^i - C_{11}^f$
	Impact on the consumer health	$RH(C)_{12} \to \max$ $\Delta C_{12}^i - C_{12}^f$
	Information on cases of poisoning	$RH(C)_{13} \to \min$ $\Delta C_{13}^i - C_{13}^f$
Control measures – $RH(K)$	Microbiological threats monitoring system	$RH(K)_1 \to \min$ $\Delta K_1^i - K_1^f$
	Verification of the microbiological hazard monitoring system	$RH(K)_2 \to \max$ $\Delta K_2^i - K_2^f$
	Chemical hazard monitoring system	$RH(K)_3 \to \min$ $\Delta K_3^i - K_3^f$
	Verification the chemical hazard monitoring system	$RH(K)_4 \to \max$ $\Delta K_4^i - K_4^f$
	Internal information system – market operator	$RH(K)_5 \to \max$ $\Delta K_5^i - K_5^f$
	Traceability system – market operator	$RH(K)_6 \to \max$ $\Delta K_6^i - K_6^f$
	The informing system about possible threats – market operator	$RH(K)_7 \to \max$ $\Delta K_7^i - K_7^f$
	National food production policy	$RH(K)_8 \to \max$ $\Delta K_8^i - K_8^f$
	Emergency situations action plan	$RH(K)_9 \to \Delta\max$ $\Delta K_9^i - K_9^f$

The absolute deviation is determined by the number of points of expert evaluation from 1 to 3, where 3 is a high level of factor, 2 is an average level of factor, 1 is a low level of factor.

Quantitative assessment of a comprehensive indicator of risk management in FSMS is based on the average value of the dynamics of change of individual groups that are part of this indicator.

The developed method is unified, as it allows to apply adjustments and corrective actions to individual factors that form the criteria of general risk management indicators for unintentional threats, which are identified using the HACCP principles.

The calculation of the overall risk management indicator is carried out by:

$$RH = \frac{\frac{\sum_{i=1}^{n_1} RH(M)i_1}{n_1} + \frac{\sum_{i=1}^{n_2} RH(C)i_2}{n_2} + \frac{\sum_{i=1}^{n_3} RH(K)i_3}{n_3}}{n_4}, \quad (4)$$

where RH – overall risk management indicator for unintentional threats identified using HACCP principles; n_1, n_2 and n_3 – the total number of factors that form each criterion ($n_1=12$, $n_2=13$, $n_3=9$); n_4 – the sum of factors that form the criterion of general risk management indicators.

The second group of indicators allows to manage the risk in FSMS on intentional threats, which are identified using the principles of VACCP, TACCP. The criteria for an overall risk management indicator are opportunities, motivation, and control measures that combine factors that characterize intentional threats of economically motivated fraud and harm.

General indicators and individual factors of this group are presented in Table 3.

The calculation of the overall risk management indicator is carried out by:

$$RV = \frac{\frac{\sum_{i=1}^{m_1} RV(O)i_1}{n_1} + \frac{\sum_{i=1}^{m_2} RV(M)i_2}{n_2} + \frac{\sum_{i=1}^{m_3} RV(K)i_3}{n_3}}{n_4}, \quad (5)$$

where RV – an overall risk management indicator for intentional threats that are identified using VACCP, TACCP principles; m_1, m_2 and m_3 – the total number of factors that form each criterion ($m_1=11$, $m_2=18$, $m_3=17$); m_4 – the sum of factors that form the criterion of general risk management indicators.

Table 3

General indicators and individual risk management factors of vulnerability analysis and critical control points (RV)

Criterion	Factors	Target function/absolute deviation
1	2	3
Opportunities – $RV(O)$	The complexity of fraud – raw materials	$RV(O)_1 \to \min$ $\Delta O_1^i - O_1^f$
	Availability of technology and knowledges for fraud – raw materials	$RV(O)_2 \to \min$ $\Delta O_2^i - O_2^f$
	The possibility of detecting a fraud – raw materials	$RV(O)_3 \to \max$ $\Delta O_3^i - O_3^f$
	Availability of technology and knowledge for fraud – the finished product	$RV(O)_4 \to \min$ $\Delta O_4^i - O_4^f$
	The possibility of detecting fraud – the finished product	$RV(O)_5 \to \max$ $\Delta O_5^i - O_5^f$
	The complexity of fraud	$RV(O)_6 \to \min$ $\Delta O_6^i - O_6^f$
	Ability to detect fraud	$RV(O)_7 \to \max$ $\Delta O_7^i - O_7^f$
	Possibility of interference in the work of production lines	$RV(O)_8 \to \min$ $\Delta O_8^i - O_8^f$
	Supply chain transparency	$RV(O)_9 \to \min$ $\Delta O_9^i - O_9^f$
	Information on cases of fraud – raw materials	$RV(O)_{10} \to \min$ $\Delta O_{10}^i - O_{10}^f$
	Information on cases of fraud – finished product	$RV(O)_{11} \to \min$ $\Delta O_{11}^i - O_{11}^f$

Continuation of Table 3

1	2	3
Motivation – $HV(M)$	Supply and pricing – raw materials	$HV(M)_1 \to \min$ $\Delta M_1^i - M_1^f$
	Valuable components – raw materials	$HV(M)_2 \to \min$ $\Delta M_2^i - M_2^f$
	Financial position – market operator	$HV(M)_3 \to \min$ $\Delta M_3^i - M_3^f$
	Management strategy – market operator	$HV(M)_4 \to \max$ $\Delta M_4^i - M_4^f$
	Corporate ethics and culture – market operator	$HV(M)_5 \to \max$ $\Delta M_5^i - M_5^f$
	Criminal offenses – market operator	$HV(M)_6 \to \min$ $\Delta M_6^i - M_6^f$
	The level of corruption in the country – market operator	$HV(M)_7 \to \min$ $\Delta M_7^i - M_7^f$
	Financial position – supplier	$HV(M)_8 \to \min$ $\Delta M_8^i - M_8^f$
	Strategy management – supplier	$HV(M)_9 \to \max$ $\Delta M_9^i - M_9^f$
	Corporate ethics and culture – supplier	$HV(M)_{10} \to \max$ $\Delta M_{10}^i - M_{10}^f$
	Criminal offenses – supplier	$HV(M)_{11} \to \min$ $\Delta M_{11}^i - M_{11}^f$
	The level of corruption in the country – supplier	$HV(M)_{12} \to \min$ $\Delta M_{12}^i - M_{12}^f$
	Financial position – market segment	$HV(M)_{13} \to \min$ $\Delta M_{13}^i - M_{13}^f$
	Criminal offenses – client	$HV(M)_{14} \to \min$ $\Delta M_{14}^i - M_{14}^f$
	Corporate ethics and culture – market segment	$HV(M)_{15} \to \max$ $\Delta M_{15}^i - M_{15}^f$
	Information on cases of falsification – market segment	$HV(M)_{16} \to \max$ $\Delta M_{16}^i - M_{16}^f$
	Level of competition – market segment	$HV(M)_{17} \to \min$ $\Delta M_{17}^i - M_{17}^f$
	Price constancy	$HV(M)_{18} \to \max$ $\Delta M_{18}^i - M_{18}^f$
Control measures – $HV(K)$	Falsification monitoring system – raw materials	$HV(K)_1 \to \max$ $\Delta K_1^i - K_1^f$
	Verification of the falsification monitoring system – raw materials	$HV(K)_2 \to \max$ $\Delta K_2^i - K_2^f$
	Falsification monitoring system – finished product	$HV(K)_3 \to \max$ $\Delta K_3^i - K_3^f$
	Verification of the falsification monitoring system – finished product	$HV(K)_4 \to \max$ $\Delta K_4^i - K_4^f$
	Information system – market operator	$HV(K)_5 \to \max$ $\Delta K_5^i - K_5^f$
	Traceability system – market operator	$HV(K)_6 \to \max$ $\Delta K_6^i - K_6^f$
	Information system – market operator	$HV(K)_7 \to \max$ $\Delta K_7^i - K_7^f$
	Corporate ethics – market operator	$HV(K)_8 \to \max$ $\Delta K_8^i - K_8^f$
	The system of informing about possible violations – market operator	$HV(K)_9 \to \max$ $\Delta K_9^i - K_9^f$
	Fraud monitoring system – supplier	$HV(K)_{10} \to \max$ $\Delta K_{10}^i - K_{10}^f$
	Traceability system – supplier	$HV(K)_{11} \to \max$ $\Delta K_{11}^i - K_{11}^f$
	Public control – supply chain	$HV(K)_{12} \to \max$ $\Delta K_{12}^i - K_{12}^f$
	Fraud monitoring – industry	$HV(K)_{13} \to \max$ $\Delta K_{13}^i - K_{13}^f$
	National food production policy	$HV(K)_{14} \to \max$ $\Delta K_{14}^i - K_{14}^f$
	Law enforcement practice – national level	$HV(K)_{15} \to \max$ $\Delta K_{15}^i - K_{15}^f$
	Law enforcement practice – global supply chain	$HV(K)_{16} \to \max$ $\Delta K_{16}^i - K_{16}^f$
	Emergency situations action plan	$HV(K)_{17} \to \max$ $\Delta K_{17}^i - K_{17}^f$

The integrated risk management indicator in the FSMS is defined as the total value of the overall risk management indicators for unintentional and intentional threats for:

$$RG = \varphi_1 \cdot RH + \varphi_2 \cdot RV, \quad (6)$$

where RG – comprehensive indicator of risk management in FSMS; φ_1 and φ_2 – weights that depend on the scope of the food market operator are based on expert judgment and satisfy the condition:

$$\sum_{i=1}^{l} \varphi_i = 1, \quad (7)$$

where l – number of weights coefficients.

7. SWOT analysis of research results

Strengths. The proposed algorithm and mathematical apparatus provides for the calculation of a comprehensive risk management indicator in the FSMS, taking into account the dynamics of changes in the values of individual factors and criteria for intentional and unintentional threats to food safety. The complex indicator is formed by the average value of all factors.

Weaknesses. The weaknesses of the algorithm include the fact that the algorithm is only a presentation of primary information to the leaders of the food safety team, it does not contain specific decisions on risk management or improvement of the FSMS.

Opportunities. It is planned to use an algorithm and mathematical apparatus to assess the risks of intentional and unintentional threats to the conditions of different food market operators.

Threats. The proposed solutions in the work are theoretical in nature. Practical approbation is necessary in the conditions of functioning of FSMS of the food market operators.

8. Conclusions

1. Based by the developed concept of risk management in food safety management systems, as well as a priori and statistical information from food market operators, an algorithm for determining a comprehensive indicator of risk management in FSMS was form. It is determined that a comprehensive assessment is formed by the average value of all individual factors of the criteria of unintentional and intentional threats.

2. The mathematical apparatus of calculation of the complex indicator of risk management in FSMS is developed. It allows to determine the levels of integrated risk management in the food safety management system by such groups as unintentional and intentional threats, taking into account the general indicators of the criteria and their factors. The overall criterion for unintentional threats, which are identified using HACCP principles, is determined by three criteria: microbiological threats, chemical threats and control measures, which in turn include a number of factors. The general indicator of the criterion for intentional threats, which are identified using the principles of VACCP and TACCP, is also determined by three criteria: opportunities, motivation and control measures, which in turn have a separate number of factors.

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