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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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 V ACCP – 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 develop 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 V ACCP, 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 V ACCP 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 VACCAP 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.
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:

\[
\begin{align*}
\text{if } F_i &\to \min, \text{ then } D = X_i - X_i^* \\
\text{if } F_i &\to \max, \text{ then } D = X_i^* - X_i \\
\end{align*}
\]

(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); \(X_i^*\) – 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 of the system state

\[
K_i = \sum_{i=1}^{n} \frac{\Delta_i}{n},
\]

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 1

| 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).

Table 2

| General indicators and individual risk management factors of hazard analysis and critical control points (HH) |
|---------------------------------------------------------------|
| Category of raw materials                                    |
| Finished product category                                    |
| Pathogenicity of pathogens                                   |
| Ensuring storage conditions – raw materials                  |
| Ensuring storage conditions – the finished product           |
| Presence of limit limits, MPC (maximum permissible concentration), MPN (maximum permissible norm) |
| The state of sanitation – raw material                        |
| The state of sanitation – finished product                   |
| Probability of cross-contamination                           |
| The presence of technological processes designed for regulation – the finished product |
| Impact on the consumer health                                |
| Information on cases of poisoning                            |

The value obtained after the implementation of FSMS (final value).

\[
\Delta = \begin{cases} 
0.5 + \frac{0.5 \cdot X_i}{\max\{\min, \max\}} & \text{if } \Delta > 0 \\
0.5 & \text{if } \Delta = 0 \\
0.5 - \frac{0.5 \cdot X_i}{\max\{\min, \max\}} & \text{if } \Delta < 0 
\end{cases}
\]

(2)

where \(\Delta\) – dynamics of change of the \(i\)-th indicator of system; \(\max\{\min, \max\}\) – 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.
The calculated overall risk management indicator is carried out by:

\[
RH = \frac{\sum_{i=1}^{n_1} RH(M)i + \sum_{i=1}^{n_2} RH(C)i + \sum_{i=1}^{n_3} RH(K)i}{n_1 + n_2 + n_3},
\]

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 VАССР, ТАССР. 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:

\[
RV = \frac{\sum_{i=1}^{n_1} RV(O)i + \sum_{i=1}^{n_2} RV(M)i + \sum_{i=1}^{n_3} RV(K)i}{n_1 + n_2 + n_3},
\]

where \(RV\) – an overall risk management indicator for intentional threats that are identified using VАССР, ТАССР principles; \(m_1, m_2\) and \(m_3\) – the total number of factors that form each criterion \((m_1=11, m_2=18, m_3=17)\); \(n_4\) – the sum of factors that form the criterion of general risk management indicators.

### Table 3

| Criterion | Factors | Target function/absolute deviation |
|-----------|---------|-------------------------------------|
| 1         | 2       | 3                                   |
| The complexity of fraud – raw materials | \(RV(0_1)\rightarrow\min\) \(\hat{O}_1-O_1^f\) |
| Availability of technology and knowledge for fraud – raw materials | \(RV(0_2)\rightarrow\min\) \(\hat{O}_2-O_2^f\) |
| The possibility of detecting a fraud – raw materials | \(RV(0_1)\rightarrow\max\) \(\hat{O}_1-O_1^f\) |
| Availability of technology and knowledge for fraud – the finished product | \(RV(0_1)\rightarrow\min\) \(\hat{O}_1-O_1^f\) |
| The possibility of detecting fraud – the finished product | \(RV(0_1)\rightarrow\max\) \(\hat{O}_1-O_1^f\) |

### Opportunities – \(RV(O)\)

| 1         | 2       | 3                                   |
| The complexity of fraud | \(RV(0_1)\rightarrow\min\) \(\hat{O}_1-O_1^f\) |
| Ability to detect fraud | \(RV(0_1)\rightarrow\max\) \(\hat{O}_1-O_1^f\) |
| Possibility of interference in the work of production lines | \(RV(0_1)\rightarrow\min\) \(\hat{O}_1-O_1^f\) |
| Supply chain transparency | \(RV(0_1)\rightarrow\min\) \(\hat{O}_1-O_1^f\) |
| Information on cases of fraud – raw materials | \(RV(0_1)\rightarrow\min\) \(\hat{O}_1-O_1^f\) |
| Information on cases of fraud – finished product | \(RV(0_1)\rightarrow\min\) \(\hat{O}_1-O_1^f\) |

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 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:

$$RG = \varphi_1 \cdot RH + \varphi_2 \cdot RV,$$

where $RG$ – comprehensive indicator of risk management in FSMS; $\varphi_1$ and $\varphi_2$ – weights that depend on the scope of the food market operator are based on expert judgment and satisfy the condition:

$$\sum_{i=1}^{l} \varphi_i = 1,$$

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 on 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 formed. 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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