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Представление и оценка рисков внедрения электронного контента в информационно-измерительные системы аэрогеофизического назначения на базе мягких вычислений

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Аннотация. Развитие беспилотных авиационных систем становится одним из ключевых направлений научно-технологического развития России. В рамках утверждённой стратегии до 2030 г. планируется формирование новой отрасли экономики, специализирующейся на создании и использовании гражданских беспилотников, определены приоритетные направления развития беспилотных технологий. Большой потенциал применения бесплотных аппаратов наблюдается в создании геопространственных баз данных. В связи с этим, при использовании автономных авиационных платформ для аэрогеофизических работ приобретают актуальность вопросы совершенствования и развития информационно-измерительных систем, применяемых на таких носителях, а также вопросы подготовки операторов систем аэрогеофизического назначения. Важное значение приобретает разработка алгоритмического и программного обеспечения информационно-измерительных систем на основе внедрения ранее уже созданного электронного контента: справочных материалов, инструкций по работе, эксплуатации приборной продукции, протоколов обработки получаемых результатов, методики принятия решений и др. Однако применение такого электронного контента несет риски снижения качества съемочных работ. Одним из способов оценки рисков является совмещение традиционного качественно-категорийного подхода современного риск-менеджмента с многоуровневой репрезентацией иерархии агрегирования экспертно-оцениваемых рисков в составе сводных и интегрального рисков путем применения аппарата мягких вычислений. Для систематизации и приоритезации рисков предлагается использование шкал градуирования и терм лингвистических переменных составляющих рисков, связанных с вероятностью возникновения снижения качества контента информационного обеспечения систем подготовки операторов, с потенциальной величиной возможного ущерба при возникновении факта снижения качества информационного обеспечения. В результате становится возможным разработка модели риск-оценки, представляющей собой процедуру специфического построения матриц последствий и вероятностей для отдельных риск-показателей оценки интеграции электронного контента в информационное обеспечение систем подготовки операторов информационно-измерительных систем аэрогеофизического назначения. Данная процедура есть логическая основа для расчета сводных и интегрального значений риск-показателей оценки, а также градуирования уровней риска.

Ключевые слова: подготовка операторов информационно-измерительных систем аэрогеофизического назначения, риск-показатели оценки интеграции, электронный контент, термы лингвистических переменных.

Soft computing-based representation and risk assessment of electronic content implementation in aerogeophysical information and measurement systems

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Abstract. The development of unmanned aircraft systems is becoming one of the key areas of Russia's scientific and technological development. Within the framework of the approved strategy until 2030, it is planned to form a new industry specializing in the creation and use of civilian drones, and priority areas for the development of unmanned technologies have been identified. The great potential for the use of unmanned vehicles is observed in the creation of geospatial databases. In this connection, when using autonomous aerial platforms for aerogeophysical works, the issues of improvement and development of information-measuring systems used on such carriers, as well as the issues of training of operators of aerogeophysical systems become relevant. The development of algorithmic and software of information-measuring systems on the basis of implementation of previously created electronic content: reference materials, instructions for work, operation of instrumentation products, protocols for processing of obtained results, decision-making techniques, etc. is becoming important. However, the application of such electronic content carries risks of reducing the quality of surveying works. One of the ways of risk assessment is to combine the traditional qualitative and categorical approach of modern risk management with multilevel representation of the hierarchy of aggregation of expert-assessed risks in the composition of summary and integral risks by applying the apparatus of soft computing. For systematization and prioritization of risks it is proposed to use gradation scales and terms of linguistic variables of risk components associated with the probability of occurrence of a decrease in the quality of content of information support of operator training systems, with the potential value of possible damage in the event of the fact of a decrease in the quality of information support. As a result, it becomes possible to develop a risk-assessment model, which is a procedure for the specific construction of matrices of consequences and probabilities for individual risk-indicators of the assessment of the integration of electronic content in the information support of training systems for operators of information-measuring systems of aerogeophysical applications. This procedure is a logical basis for calculation of summary and integral values of risk-indicators of assessment, as well as gradation of risk levels.

Keywords: training of operators of information-measuring systems of aerogeophysical application, risk-indicators of integration assessment, electronic content, terms of linguistic variables.

Introduction

The List of priority areas of scientific and technological development of Russia, approved by Decree of the President of the Russian Federation dated June 18, 2024 No. 529, includes "Intelligent transport and telecommunication systems, including autonomous vehicles" and specifies the List of the most important science-intensive technologies, which highlights such areas as:

–transport technologies for various areas of application (sea, land, air), including unmanned and autonomous systems;

–monitoring and forecasting the state of the environment and climate change (including key areas of the World Ocean, the seas of Russia, the Arctic and Antarctica), technologies for preventing and reducing the risks of natural and man-made emergencies, negative socio-economic consequences.

In this regard, the development of information and measurement systems for aerogeophysical purposes, increasing the efficiency of organizing aerogeophysical research, optimizing data processing processes, ensuring the reliability of the information received, and training operators of such systems are becoming especially relevant.

Risk assessment in the development of information and measurement systems, the efficiency of using previously created electronic content is a critically important process that ensures the reliability and efficiency of systems, minimizes possible losses and optimizes the costs of their implementation [1]. To improve the quality of the assessment, the model must be iterative.

Risk assessment of integration of electronic content into information support

One of the main blocks of the iterative risk assessment model for integrating electronic content (EC) into the information support (IS) of the training systems for operators of information and measurement systems for aerogeophysical purposes (IMS AP) includes risk assessment based on soft computing. The logical and algorithmic implementation of the block is based on regulatory and technical documents of modern risk management [2–4] and is used, among other things, in information systems [5–7].

The assessment of any risk of EC integration assumes a reasonable construction of the matrix of this risk assessment and is the conclusion of the probability of occurrence of unacceptable consequences and potential damage. Risk assessment indicators are determined by an iterative procedure through aggregation of the values of simpler indicators included in their composition, are presented through aggregating associations of i…j risk indicators from the composition of the family of the simplest indicators. A large number of levels of such aggregation leads to the synthesis of a hierarchy of risk indicators.

To systematize and prioritize risks, it is proposed to use the following scales for grading risk components, obtained by processing an expert survey using methods of analytical hierarchy of matrices of pairwise comparisons of individual opinions of each of the k surveyed experts:

–the probability of a decrease in the quality of the content of the IS systems for training operators of the IMS AP due to the integration of EC materials into their composition (Table 1) (the probability pij of a decrease in the quality of the content, where i and j are the elementary indicators of the quality of the IS, the levels of decrease are represented by a scale of values of the verbal interpretation of the requested data);

–potential value of possible damage in the event of a decrease in the quality of the IS of the training systems for operators of the IMS AP (Table 2) (damage y_{ij}, where i and j are elementary indicators of the quality of the IS, the levels of damage are represented by a scale of values of the verbal interpretation of the requested data).

The levels of risk of reducing the quality of the content of the information resource are determined in accordance with the opinions of experts (the number of experts is k), and u_{ij} is a multiplicative convolution of the levels of risk manifestation according to the elementary indicators of the quality of the information resource, and are measured on the basis of ordinal or quantitative scales.

Using the results of studies [8–11], a five-level scale of risk levels with color identification by gray gradation can be implemented in the model: from black (highest risk) to white (lowest risk) (Table 3).

Table 1

Scale of levels of probability of reduction in the quality of IS systems for training operators of the IMS AP due to the integration of EC into their composition

№	Verbal name of levels and their identification designation	Description of the distinctive creature, corresponding boundary features	General explanations
1	Definitely p_{ij}: DEFINITELY	It is obvious that the quality of the means of IS systems for training operators of the IMS AP due to the integration of EC into their composition will be low	The highest probability of occurrence
2	Скорее всего More likely p_{ij}: «VERY LIKELY»	It is very possible that the quality of the means of IS systems for training operators of the IMS AP will be reduced due to the integration of EC into their composition	

End of Table 1

№	Verbal name of levels and their identification designation	Description of the distinctive creature, corresponding boundary features	General explanations
3	Quite possible p_{ij}: EXPECTED	There is reason to believe that the quality of the means of IS systems for training operators of the IMS AP will be low due to the integration of EC into their composition	
4	Minimum allowable p_{ij}: UNLIKELY	Individual manifestations and properties of the content used can lead to a decrease in the quality of the IS systems for training operators of the IMS AP due to the integration of EC into their composition	
5	Rarely occurring, extremely rare manifestation p_{ij}: EXTREMELY RARE	There is no reason to believe (expect) that the quality of the IS systems for training IMS AP operators will be reduced due to the integration of EC into their composition	Least likely

Table 2

Scale of damage levels from the reduction in the quality of the IS systems for training operators of the IMS AP due to the integration of EC into their composition

№	Verbal name of levels and their identification designation	Description of the distinctive creature, corresponding boundary features		
		Signs of a decrease in the efficiency of training of IMS AP operators using automated tools, EC		
		Motivational, psychological and organizational	Motivational, psychological and organizational	Motivational, psychological and organizational
I	Unimportant, neglected small, super small y_{ij}: ULTRA SMALL	There is no evidence of a decrease in the motivation of the specialists being trained; there are isolated, non-systemic facts of a decrease in motivation	Minor, comparable with the measurement method error	It is possible to eliminate the shortcomings of the use of IS tools by the organizers of the process of training IMS AP operators
II	Noticeable, small, visible y_{ij}: VISIBLE	A fragmentary decrease in the motivation of trained specialists when working with the use of automated training tools, EC is noted	Average, noticeably significant, requiring intensification of preparation	It is possible to eliminate the shortcomings of the use of IS tools by specialized support units, with the involvement of additional data sources
III	Noticeable, moderately significant, average y_{ij}: AVERAGE	A systematic decrease in the motivation of trained specialists to work with the use of automated training tools, electronic content, in general, is noted	Significantly important, high, requiring compensation through additional time and other resources	It is possible to eliminate deficiencies in the application and operation of IS tools by specialized external organizations - representatives of the developer, with the involvement of consulting and competence support from external providers

End of Table 2

№	Verbal name of levels and their identification designation	Description of the distinctive creature, corresponding boundary features		
		Signs of a decrease in the efficiency of training of IMS AP operators using automated tools, EC		
		Motivational, psychological and organizational	Motivational, psychological and organizational	Motivational, psychological and organizational
IV	Essential, significant, large, strong y_{ij}: STRONG	A critical decrease in the motivation of trained specialists is noted both for work with the use of individual means of automated training, and with electronic content in general	Very important, large, requiring priority and significant compensation through additional time and other resources	There remains a small chance to eliminate the shortcomings of the application and operation of IS tools, but they are possible only with the involvement of the developer.
V	Critical, catastrophically strong, irreparable y_{ij}: VERY STRONG	A complete loss of motivation of trained specialists is noted both for work with the use of individual means of training automation, and with electronic content in general.	Irreparable losses of IMS AP operators within the current training course	The identified software and technological shortcomings, structural and semantic errors in the implementation of the IS require a complete reworking of the automation tool for training, which has damaged the training course for IMS AP operators

Table 3

Scale of grading the levels of risk of reducing the quality of content of the IO systems for training operators of the IMS AP due to the integration of EC into their composition

№	Verbal name of levels and their identification designation	Description of the distinctive creature, corresponding boundary features	Fast color identification, conventional bar-identification of the term of a linguistic variable
1	Critically dangerous, emergency $r_k(u_{ij})$: EMERGENCY	Requires immediate and massively decisive corrective actions with the involvement of all available resources (from training managers to developers of the means of IS systems for training operators of the IMS AP)	
2	Dangerous, requiring urgent response $r_k(u_{ij})$: DANGEROUS	Requires urgent corrective actions with partial and planned involvement of external resources, as well as informing the developer of the IS tool, to eliminate the identified deficiencies	
3	Controlled, controlled-compensated $r_k(u_{ij})$: CONTROLLED	Requires planned corrective actions with partial involvement of additional resources, as well as development of the full implementation of all functional capabilities of the means of IS systems for training operators of the IMS AP, embedded in it by the developer	

End of Table 3

№	Verbal name of levels and their identification designation	Description of the distinctive creature, corresponding boundary features	Fast color identification, conventional bar-identification of the term of a linguistic variable
4	Localizable, low $r_k(u_{ij})$: LOW	It is hedged and/or localized within the framework of standard schemes of daily functioning, damage is prevented in the volume of planned mandatory procedures of fine-tuning, individualization of preparation	
5	Insignificant, not influencing $r_k(u_{ij})$: INSIGNIFICANT	It is monitored periodically in order to promptly identify changes, discrepancies, etc.	

Application of soft computing apparatus to assess the risk of integrating electronic content into information support

The need for mathematical convolution of the values of the simplest risks into the values of the summary $r_к$ and the integral R_0 risk indicators for assessing the integration of the EC into the IS of the operator training systems of the IMS AP determines the need for a quantitative expression of the specified gradations of the risk components p_{ij} and y_{ij} based on the application of the mathematical apparatus of soft computing: the algebra of linguistic variables using the theory of fuzzy sets.

Thus, in particular, based on the apparatus of linguistic variables indicated in Tables 1 and 2, the designations of the levels that constitute the simplest risks of integrating EC into the IS of the systems for training operators of the IMS AP can be considered as the corresponding terms of the following linguistic variables:

$$L_1 = \text{<the likelihood of a decrease in the quality of the IS content>}; \quad (1)$$

$$L_2 = \text{<damage from the reduction of the quality of the content of the IS>}. \quad (2)$$

The theoretical basis (the basic concepts, the corresponding algebras from the theory of fuzzy sets, etc.) of working with linguistic variables (1) and (2) corresponds to the section of modern mathematics of soft computing – the theory of linguistic variables, the theory of fuzzy sets [12–14]. In view of the above, in substantiating and synthesizing the presented quality assessment model, it is the specific aspects of the scientific and methodological application of the introduced linguistic variables L_1 and L_2, (1) and (2), that are investigated, while the aspects of constructing their term sets, assigning specific variable identifiers, etc. can be attributed to the generally known. In general, each of the linguistic variables L_1 and L_2 is defined as a certain set-theoretic generalization of $L^\wedge$:

$$L^\wedge = \langle \beta, F^\wedge(\beta), X^\wedge, G^\wedge, N^\wedge \rangle, \quad (3)$$

where β – a verbal identifier that acts as a name for a linguistic variable; $F^\wedge(\beta)$ – a family of values (terms) of a linguistic variable β, the so-called term set. This is a family (i.e. indexed set) of verbalized values of a linguistic variable β, in which each of such terms, values, is a fuzzy variable with domain of definition $X^\wedge$; $G^\wedge$ is a syntax rule – grammar that generates concretized values $\alpha^\wedge$ of fuzzy variables for terms of the linguistic variable β ($\alpha^\wedge \in F^\wedge(\beta)$)); $N^\wedge$ is a semantic rule that determines the correspondence of each fuzzy variable $\alpha^\wedge \in F^\wedge(\beta)$) to the corresponding fuzzy subset [15].

The main source of data on non-numerical "measurements" of the simplest risks and their components in this subject area is a human expert. For him, the essence of such a "non-numerical measurement" for the value of a particular risk indicator consists in a non-metric assessment of the degree of coincidence of the current picture of the possible occurrence of damage according to the risk indicator

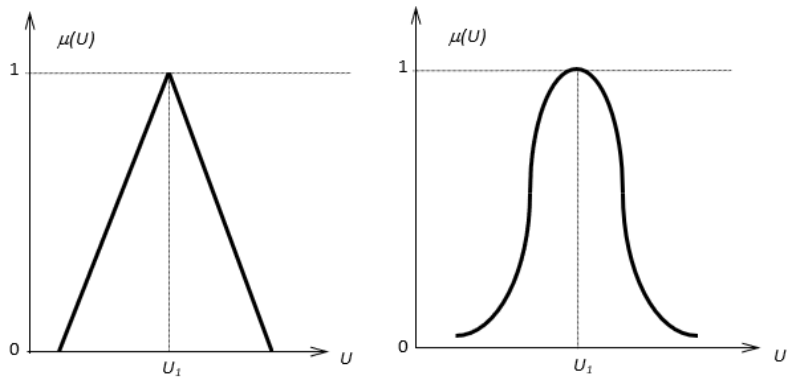
under consideration with some reference model of the ideal picture of the current situation. It is the degree of such coincidence with the specified ideal that in the mind of the expert acts as a measure of non-instrumental measurement, the difference:

$$\Delta U_i = U_i - U_0, \tag{4}$$

where U_i –level of risk manifestation according to the *i*-th risk assessment indicator; U_o –the reference, ideal level of risk manifestation for the *i*-th risk assessment indicator, recognized by the expert.

To represent the risk components p_{ij} and y_{ij} based on the application of the mathematical apparatus of soft computing as linguistic variables L1 and L2, i.e. (1) and (2), of the mathematical form $L^{\wedge}$ in accordance with (3), with the term set of values defined on the scales presented in Tables 1 and 2, a correspondence was established between the gradations of the assessment scales of the specified parameters as fuzzy sets identified as terms (values) of the specified linguistic variables. In other words, it is methodologically accepted that when assessing the components of the simplest risks, experts are required to use precisely the terms – values of the linguistic variables $L1$ and $L2$, respectively. The synthesis of terms, fuzzy sets for linguistic assessment scales, is implemented using well-known methods for constructing membership functions of fuzzy numbers [15].

In particular, within the framework of the proposed model of iterative risk assessment of the integration of EC into the IS of the training systems for operators of the IMS AP, the well-known method of relative frequencies [15] is used as a mathematical apparatus for synthesizing the membership functions of fuzzy numbers - terms of linguistic variables $L1$ and $L2$. In this case, the values of linguistic variables, according to the methods from [15], can be specified (i.e. synthesized) as fuzzy numbers in the form of *(L-R)*-functions, or as so-called triangular fuzzy numbers (TFN), which is shown in Fig. 1.



а *б*

Рис. 1. Исследованные функции принадлежности для термов лингвистических переменных в форме:
а – треугольных нечетких чисел; *б* – (*L-R*)-функций

Fig. 1. Investigated membership functions for terms of linguistic variables in the form of:
а – triangular fuzzy numbers; *б* – (L-R)-functions

Based on the descriptions of the scales of the levels of probability of reduction and the levels of the magnitude of potential damage from the reduction in the quality of content for the IS systems for training operators of the IMS AP due to the integration of the EC materials into their composition, shown in Tables 1 and 2, the membership functions of fuzzy sets $\mu(u)$ are analytically determined, defining the terms-values of the linguistic variables L_1 and L_2. For such a synthesis of $\mu(u)$, a standardized mathematical submodel for calculating membership functions based on expert assessment data is used. This submodel allows calculating the membership functions μ_T^L of the terms of the variables L_1 and L_2 both in the form of *(L-R)*-functions and in the form of triangular fuzzy numbers (TFN).

The developed model of iterative risk assessment of integration of EC into IS systems for training operators of IMS AP is invariant in application to the specified submodel, methodology, apparatus,

etc. of calculation of membership functions μ_T^L of term-values of linguistic variables L_1 and L_2. Application of μ_T^L with TNC-form is typical for situations of rough, accelerated risk assessment, in case of more detailed and substantiated analysis of risks of reduction of quality of content of IS systems for training operators of IMS AP due to integration of EC materials into their composition, due to implementation of "more cautious" approach to risk assessment, it is necessary to apply μ_T^L in the form of *(L-R)*-functions.

The calculation of μ_T^L in the form of (*L-R*)-functions, according to the adopted calculation submodel, is determined for each term-gradation of linguistic variables L_1 and L_2, from the ratio

$$\mu_T{}^L(U) = \exp(-a(T-U)^2), \tag{5}$$

where T – the median value of the term for μ_T^L equal to one, as applied to the scales of variables $L_1$and L_2 shown in Tables 1 and 2; $a = 4Ln\frac{0,5}{b^{\wedge 2}}$ is the matching coefficient; $b\wedge$ is the distance between the inflection points: the points at which the graph of the function μ_T^L, according to (5), takes on the value 0.5.

The main parameters for calculating the term-gradations of linguistic variables L_1 and L_2, according to (5), are given in Table 4.

The results of calculating the membership functions μ_T^L of all terms for all levels of the scales of linguistic variables L_1 and L_2, (1) and (2), according to formula (5) make it possible to obtain quantitative scales for assessing these linguistic variables L_1 and L_2. These quantitative scales make it possible to make the transition from verbal expert assessments to their fuzzy numerical values with μ_T^L.

The membership functions of term-gradations (meanings) of linguistic variables L_1 and L_2 in the form of *(L-R)*-functions correspond to the following conditions:

$$\left[\mu_{T1}^L(U_1) = 1; \quad \mu_{T5}^L(U_5) = 5\right];$$

$$(\vee\beta\wedge \in B\wedge \setminus \{\beta\wedge\})\ (0 < \sup u \in U\ \mu_{T_i \cap T_{i+1}}^L(U) < 1);$$

$$(\vee\beta\wedge \in B\wedge)\ \ (u \in U) : (\mu_T^L(U) = 1);$$

$$(\vee B\wedge)\ (u_1 \in R_1)\ (u_2 \in R_2)\ ((u \in U)(u_1 < u < u_2)).$$

Table 4

Main parameters for calculating term-gradations of linguistic variables L_1 and L_2

№ п/п	Terms for L_1	Value at $\mu_T^{L1} = 1$	Terms for L_2	Value at $\mu_T^{L2} = 1$	A refined form of analytical calculation of the membership function of terms
1	No probability	0	No damage	0	$\mu_T^L(U) = 1–2U$
2	Extremely rare	1	Ultra-small	1	$\mu_T^L(U) = e^{-13,1(1-U)^2}$
3	Unlikely	3	Visible	3	$\mu_T^L(U) = e^{-1,46(1-U)^2}$
4	Expected	5	Average	5	$\mu_T^L(U) = e^{-0,35(1-U)^2}$
5	Very likely	7	Strong	7	$\mu_T^L(U) = e^{-0,27(1-U)^2}$
6	Definitely	9	Very strong	9	$\mu_T^L(U) = e^{-0,16(1-U)^2}$

Thus, the set of membership functions of fuzzy numbers – terms (values) of linguistic variables L_1 and L_2 together form a quantitative scale for conducting fuzzy assessment of the corresponding components of the simplest risks of reducing the quality of the content of the IS systems for training operators of the IMS AP due to the integration of EC materials into their composition.

A generalized form of graphical representation of such a scale for the simplest risk indicator is given using the example of the linguistic variable L_1 and is presented in Fig. 2.

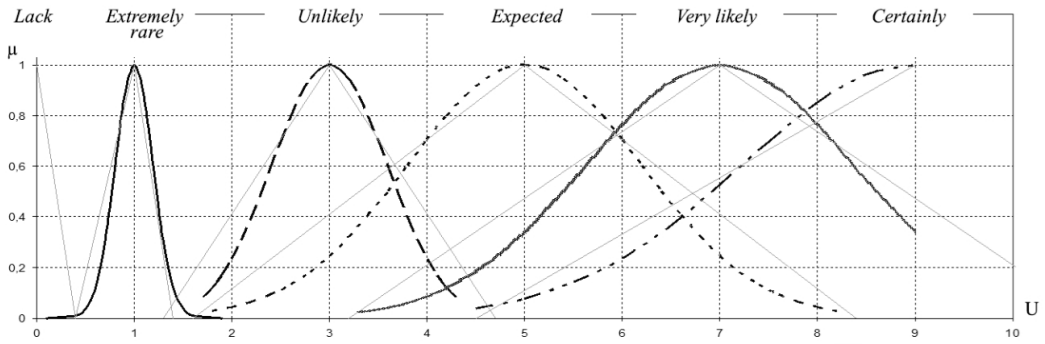


Рис. 2. Представление шкалы уровней вероятности снижения качества ИО из-за интеграции в их состав ЭК (табл. 1) в виде терм-множества значений лингвистической переменной L_1

Fig. 2. Representation of the probability level scale for the decrease in information support quality due to the integration of electronic content (Table 1) in the form of a term set of values for the linguistic variable L_1

Further, it is possible to interpret the meaning of the scales of the simplest risk indicators in the hierarchy of risk assessment of a decrease in the quality of the content of the IS systems for training APP operators due to the integration of EC materials into their composition as a product of membership functions μ_T^L of fuzzy numbers - term values of linguistic variables L_1 and L_2 for each of the simplest risk indicators.

Methodically, according to the classical canons of risk management, risk assessment is a synthesis of the matrix of consequences and probabilities, which links input parameters such as the values of the assessment of the probabilities of adverse events and the values of the assessment of potential damage (at the input) with the integral conclusion on the level of risk-hazard (at the output). The response to the risk value in the form of corrective, influencing complexes of measures is the essence of risk management. Thus, the block of assessment of the simplest risks based on soft calculations of the developed risk assessment model, in essence, is a procedure for the specific construction of matrices of consequences and probabilities for individual risk indicators of assessment of the integration of EC into the IS of the systems for training operators of the IMS AP. This procedure is a logical basis for calculating the summary and integral values of the risk indicators of assessment.

Accordingly, for the iterative risk assessment model of EC integration into the information support of the IMS AP operator training systems, the block of simplest risk assessment based on soft computing of the developed risk assessment model is reduced to a logical and mathematical apparatus for ensuring the calculation of risk assessment values by indicators in accordance with the structure of the risk assessment hierarchy while preserving the essence of the logic of synthesis of the corresponding consequence and probability matrices. The specified logic consists of the traditionally accepted grading of risk levels (danger of damage) with the corresponding differential-color representation. An example of this grading of risk levels with the corresponding differential-color representation for the purposes of iterative risk assessment of EC integration into the information support of the IMS AP operator training systems, taken as a basis in the developed model and shown in Table 3, is shown in Fig. 3.

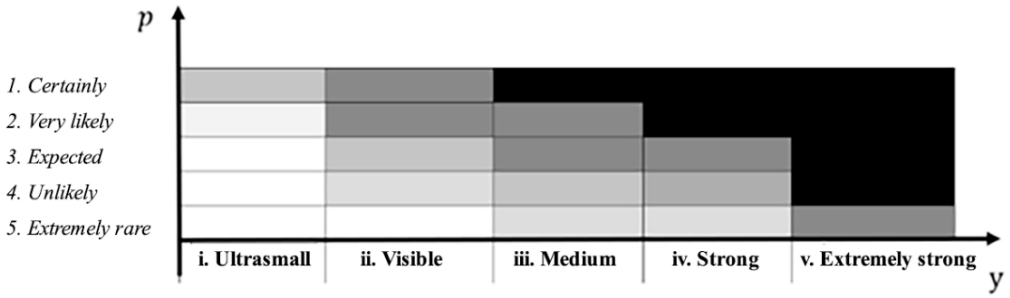


Рис. 3. Вариант матрицы последствий и вероятностей оценки рисков по одному из простейших показателей

Fig. 3. A variant of the matrix of consequences and probabilities of risk assessment based on one of the simple indicators

The presented interpretation of the meaning of the scales of the simplest risk indicators in the hierarchy of risk assessment of the reduction in the quality of the content of the IS systems for training operators of the IMS AP due to the integration of EC materials into their composition as a product of membership functions μ_T^L of fuzzy numbers – term values of linguistic variables L_1 and L_2 makes it possible to consider each of the cells of the matrix of consequences and probabilities of risk assessment by the simplest indicator as a fuzzy number L_{ij}:

$$L_{ij}^{*} = \langle \text{the value of the assessment for this risk indicator} \rangle$$

where, in relation to the simplest risk indicators, it is true that the specified value L_{ij}^{*} is the product of fuzzy numbers of the i-th term from L_1 and the j-th term from L_2:

$$L_{ij}^{*} = L^{i}_{1} \times L^{j}_{2}.$$

Membership functions $\mu_T^{L^{*}_{ij}}$ for the values of L_{ij}^{*} are found according to the rules of multiplication operations of fuzzy numbers from the algebra of soft computing [15].

Conclusion

The visual appearance of the matrix of consequences and probabilities of risk assessment by one of the simplest indicators, in which the expert, risk assessor, works, can be compared with a fuzzy-numeric representation that expresses his assessing opinion quantitatively in the categories of fuzzy numbers. This makes it possible to use such fuzzy numerical expressions of assessments by the simplest indicators in the course of convolution of these assessments into summary and integral risk indicators of assessment of the integration of EC into the IS of the operator training systems of the IMS AP, based on the algebra of soft computing. In this case, the matrix of consequences and probabilities of risk assessment by one, any of the simplest indicators is a scale of risk assessment of the integration of EC into the IS of the operator training systems by this indicator. Then the assessment of its current value by the expert assessor consists in the justified identification of the corresponding cell of the above-mentioned matrix of consequences and probabilities, as well as the fuzzy value of the risk assessment corresponding to this cell. The essence of the specified risk assessment process is shown in Fig. 4. Consequently, on the basis of (1) and (2), the risk assessment scales themselves based on the simplest indicators and the assessments based on these scales are reduced to one-dimensional fuzzy scales and the values of the assessments on them, as the value of L_{ij}^{*}.

The constructive innovation of the developed model of iterative risk assessment of EC integration into information support of IMS AP operator training system is the combination of the traditional qualitative-categorical approach of modern risk management with a multi-level representation of the hierarchy of aggregation of expert-assessed risks in the composition of summary and integral risks of the

considered integration by using the soft computing apparatus. This approach made it possible to implement the transition from a qualitative-conceptual representation of the risk of the considered integration to a quantitative one.

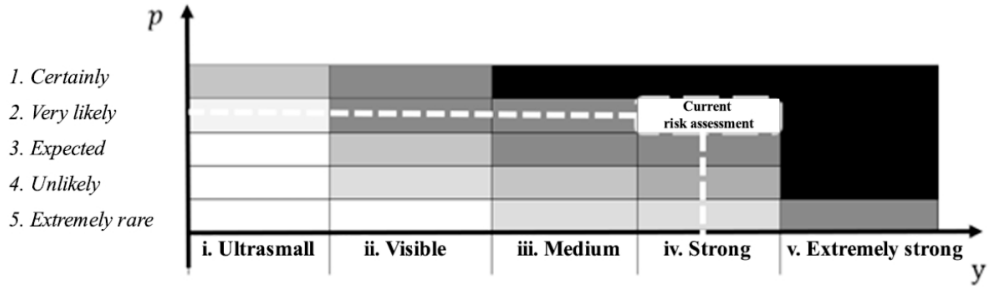


Рис. 4. Существо оценивания риска по простейшему показателю

Fig. 4. The essence of risk assessment based on the simple indicator

Thus, the proposed block of assessment of the simplest (directly measured or assessed) risks in the model of iterative risk assessment of EC integration into information support of IMS AP operator training systems and the approach to establishing the value of the current risk for this simplest indicator makes it possible to use such values in calculating the values of summary and integral risk indicators.

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