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METHOD OF INFORMATIONAL RISK RANGE EVALUATION IN DECISION MAKING

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МЕТОД ОЦІНКИ ВЕЛИЧИНИ ІНФОРМАЦІЙНОГО РИЗИКУ ПРИ ПРИЙНЯТТІ РІШЕНЬ

Abstract. Looks into evaluation of information provision probability from different sources, based on use of linguistic variables. Formation of functions appurtenant for its unclear variables provides for adoption of decisions by the decision maker, in conditions of nonprobabilistic equivocation. The development of market relations in Ukraine increases the independence and responsibility of enterprises in justifying and making management decisions that ensure their effective, competitive activities. As a result of the analysis, it is determined that the condition of economic facilities can be described and determined by the decision-maker, in the presence of the necessary information. The confidence of the decision-maker in the information received is different and the decisions made have a correspondingly different level of information risk. It is important to substantiate the procedure for assessing the numerical extent of information risk in decision-making based on the information obtained in conditions of uncertainty. The use of a linguistic variable in the processing of expert data presented in the form of a matrix of binary relations of values of the membership function, which allowed to move to further processing of knowledge to support decision-making in the management of industrial, commercial, financial and other activities. As a mathematical model for estimating the numerical measure of information risk when making decisions based on the information obtained in conditions of non-stochastic uncertainty, a model has been developed to model natural language uncertainties, which differs from existing ones by formalizing knowledge taking into account uncertainty of input information. Making such a clear decision in a fuzzy environment has appropriate values of effectiveness and risk. The paper proposes all the functions and accessories of indicators of both quantitative nature and qualitative nature to bring their values in the field of definition to one scale. Then the indicator of the effectiveness of decision-making will be a measure of the clarity of the cross-section of fuzzy subsets, which correspond to the introduced indicators of information risk. The condition of economic facilities can be described and determined by the decision-maker, if the necessary information is available. Decision-making on the numerical measure of information risk must be determined by a set of basic indicators (criteria), which can be both quantitative and qualitative in nature. Predictive values of indicators should be determined in conditions of nonstochastic uncertainty. In this case, the indicators of a quantitative nature can be determined by fuzzy triangular numbers, which implement a high level of confidence in the subjective judgments of experts. Indicators of qualitative nature should be presented in linguistic variables. The values of the indicators of qualitative nature that are predicted must be considered for all fuzzy variable terms-sets of linguistic variables introduced into consideration. For any fuzzy variable, the introduction to the consideration of a clear set of values as carriers of the α-level of its membership function allows to reduce to a single interpretation of the predicted values of indicators of quantitative and qualitative nature in terms of non-stochastic uncertainty.

Keywords: decision maker; linguistic variable; informational risk; numerical measure; nonprobabilistic equivocation.

Анотація. У статті визначено, що розвиток ринкових відносин в Україні підвищує самостійність і відповідальність підприємств при обґрунтуванні й прийнятті управлінських рішень, які забезпечують ефективну, конкурентну їх діяльність. У результаті проведеного аналізу визначено, що стан народно-господарських об'єктів може бути описаний і визначений особою, що приймає рішення, при наявності необхідної інформації. Довіра особи, що приймає рішення, до отриманої інформації різна й рішення, що приймаються, мають відповідно різний рівень інформаційного ризику. Актуальним є обґрунтування процедури оцінки чисельної міри інформаційного ризику при прийнятті рішень на основі отриманої інформації в умовах невизначеності. Обґрунтовано використання лінгвістичної змінної при обробці експертних даних, представлених у вигляді матриці бінарних відносин значень функції приналежності, що дозволило перейти до подальшої обробки знань для підтримки прийняття рішень при управлінні виробничою, комерційною, фінансовою та іншими видами діяльності. В якості математичної моделі оцінки чисельної міри інформаційного ризику при прийнятті рішень на основі отриманої інформації в умовах нестохастичної невизначеності розроблена модель, що дозволяє моделювати невизначеності природної мови, яка відрізняється від існуючих формалізацією знань з урахуванням невизначеності вхідної інформації, використанням нечітких підмножин. Прийняття такого чіткого рішення в умовах нечіткого середовища має відповідні значення показників ефективності та ризику. У роботі запропоновано усі функції й приналежності показників як кількісної природи, так і якісної природи, призвести їх значення області визначення до однієї шкали виміру. В якості показника ефективності прийняття рішення обґрунтована міра чіткості перерізу нечітких підмножин, які відповідають показникам інформаційного ризику. Розвиток ринкових відносин в Україні підвищує самостійність і відповідальність підприємств при обґрунтуванні й прийнятті управлінських рішень, що забезпечують ефективну, конкурентну їх діяльність. Стан народно-господарських об'єктів може бути описаний і визначений особою, що приймає рішення, при наявності необхідної інформації. Прийняття рішення щодо чисельної міри інформаційного ризику необхідно визначати за сукупністю основних показників (критеріїв), які можуть мати як кількісну, так і якісну природу. Прогнозовані значення показників необхідно визначати в умовах нестохастичної невизначеності. При цьому показники кількісної природи можуть бути визначені нечіткими трикутними числами, які реалізують високу довіру до суб'єктивних суджень експертів. Показники якісної природи доцільно подавати лінгвістичними змінними. Значення показників якісної природи, які прогнозуються, необхідно розглядати для всіх, введених до розгляду, нечітких змінних терм-множин лінгвістичних змінних. Для будь-якої нечіткої змінної введення до розгляду чіткої множини значень як носіїв α-рівня її функції приналежності дозволяє звести до єдиного тлумачення прогнозовані значення показників кількісної та якісної природи в умовах нестохастичної невизначеності. Тоді показником ефективності прийняття рішення буде виступати міра чіткості перерізу нечітких підмножин, які відповідають введеним до розгляду показникам інформаційного ризику.

Ключові слова: особа, що приймає рішення; лінгвістична змінна; інформаційний ризик; чисельна міра; нестохастична невизначеність.

Introduction

Development of market economy in Ukraine enhances independency and responsibility of companies upon justification and adoption of managerial decisions, providing for effective, competitive activities. Results of production, commercial, financial and other types of activities depend on various factors, which are on different level of interconnection between each other and final performance indicators of the company. Their interconnection, interoperability and effect on final performance indicators of the companies vary in their power, character and development time.

The state of national economic facilities (production enterprises, distribution points, etc.) can be described and determined by the decision maker in case of necessary information availability. From functional purpose point of view, all objects can be divided into stationary and mobile. According to [1], the information support of the decision maker about stationary and mobile objects can be implemented from the following sources of information: technical (economic) intelligence, covert intelligence, space intelligence and the media. Information on stationary and moving objects of interest can be obtained for decision makers from any of the aforementioned sources of information. Depending on the functional purpose of the object, the "trust" of the decision maker in the received information of the information source will be different and the decision maker will take his decisions with a different level of information risk.

The purpose of the article is to justify the procedure for assessing information risk numerical measure while making decisions based on the information received.

Ease of Use

Let's introduce into consideration events $A_{s,q}^{(r)}$ and $A_{\bar{s},q}^{(r)}$, consisting from, that content information $r=\overline{1,R}$ for s stationary object, where $s=\overline{1,S}$, and for $\bar{s}$ moving object, where $\bar{s}=\overline{1,\bar{S}}$, will be received from q information source, where $q=\overline{1,4}$. Then the probability of events will be a numerical measure of $P(A_{s,q}^{(r)})$ and $P(A_{\bar{s},q}^{(r)})$ information risk when making a decision.

An acceptable assessment approach $P(A_{s,q}^{(r)})$ and $P(A_{\bar{s},q}^{(r)})$ under conditions of non-stochastic uncertainty leads to introduction of a linguistic variable β_s = <"Event probability value $A_{s,q}^{(r)}$"> and $\beta_{\bar{s}}$ = <"Event probability value $A_{\bar{s},q}^{(r)}$">. According to [3], a linguistic variable is a tuple $<\beta, S(\beta), X, G, M>$, where β – name of a linguistic variable; $S(\beta)$ – term set of a linguistic variable β elements of which $\alpha_i, i=\overline{1,n}$ – name of fuzzy variable $<\alpha, X, \tilde{C}(\alpha)>$ as linguistic values of a linguistic variable, where X – domain of fuzzy variables, $\tilde{C}(\alpha_i)=\left\{\mu_{\tilde{C}(\alpha_i)}(x)/x\right\}$, $x \in X$, $\mu_{\tilde{C}(\alpha_i)}(x)$ – membership function value; G – syntax rule designating a variable name $\alpha \in S(\beta)$ as verbal values of a linguistic variable; M – a syntax rule that matches each variable $\alpha \in S(\beta)$ fuzzy set $\tilde{C}(\alpha)$ [2-5].

Based on the subjective idea of the decision maker about the considered information sources intelligence capabilities, for the linguistic variables introduced into consideration, term sets containing the following values of the fuzzy variable α can be determined: α_1 – insignificant value of event probabilities $A_{s,q}^{(r)}, A_{\bar{s},q}^{(r)}$; α_2 – nearly insignificant value of event probabilities $A_{s,q}^{(r)}, A_{\bar{s},q}^{(r)}$; α_3 – significant value of event probabilities $A_{s,q}^{(r)}, A_{\bar{s},q}^{(r)}$; α_4 – high value of event probabilities $A_{s,q}^{(r)}, A_{\bar{s},q}^{(r)}$.

The contents of the conditions that must be satisfied generated for each value of the fuzzy variable $\alpha \in S(\beta)$ membership functions are as follows [2, 3]. Let $X \subseteq R$, where R – set of real numbers, $x_1=\inf X$ and $x_2=\sup X$. If $S(\beta)=\{\alpha_1,\alpha_2,\alpha_3,\alpha_4\}$, then the set $S(\beta)$ is sorted by condition:

$$(\forall \alpha_i \in S(\beta))(\forall \alpha_j \in S(\beta)\left\langle i<j \leftrightarrow (\exists x \in \tilde{C}_{(\alpha_i)}(x)\right\rangle (\forall y \in \tilde{C}_{(\alpha_i)}(x)/(x>y)). \tag{1}$$

This means that a term that has a carrier (membership function) located to the left receives a smaller number and the term set of any linguistic variable satisfies the conditions $\mu_{\tilde{C}(\alpha_i)}(x_i)=1;\ i=\overline{1,m},$ and $i=m, \alpha_i \in S(\beta)$, which means – membership functions of a fuzzy variable (terms) extreme values cannot have the form of bell-shaped curves, which is due to the location of these terms in an ordered set $S(\beta)$.

$$(\forall \alpha_i \in S(\beta)/\alpha_m)(0<\sup_{x \in X} \mu_{\tilde{C}(\alpha_i)\cap\tilde{C}(\alpha_{i+1})}(x)<1), \tag{2}$$

which means inadmissibility in $S(\beta)$ terms when there is no natural delimitation of concepts approximated by terms.

$$\forall \alpha_i \in S(\beta))(\exists x \in X)(\mu_{\tilde{C}(\alpha_i)}(x)=1), \tag{3}$$

which means – for any value of a fuzzy variable α there is one $x \in X$ for which the membership function is equal to one.

$$(\forall \beta)(\exists x_1 \in R)(\exists x_2 \in R)((\forall x \in X)(x_1 < x < x_2)), \tag{4}$$

which confirms the fact that in any control problem there is a physical restriction of numerical values on the set defining the domain of the linguistic variable in question definition X.

Based on these properties and practical applications of the expected result and the physical (technical) capabilities of the considered sources of information, the researcher agrees with the decision maker the domain of linguistic variables β_s and $\beta_{\bar{s}}$ definition in the form:

X=(0,05;0,1;0,15;0,2;0,25;0,3;0,35;0,4;0,45 ;0,5;0,6;0,65; 0,7;0,75;0,8;0,85),

where accepted $P(A^{(r)}_{s,q}) = P(A^{(r)}_{\bar{s,q}})$ <0,05 – indicate the insignificance of information sources in the information support system and $P(A^{(r)}_{s,q}) = P(A^{(r)}_{\bar{s,q}})$ <0,85 – technically not feasible considered information sources.

In addition, the decision maker determines that the term "Insignificant probability" is associated with the range $x \in X$ type ($x_1 = 0{,}05$; $x_2 = 0{,}1$; $x_3 = 0{,}15$; $x_4 = 0{,}2$; $x_5 = 0{,}25$); the term "Almost significant probability" – with the range ($x_5 = 0{,}25$; $x_6 = 0{,}3$; $x_7 = 0{,}35$; $x_8 = 0{,}4$; $x_9 = 0{,}45$); term "Significant probability" – with the range ($x_9 = 0{,}45$; $x_{10} =$ 0,5; $x_{11} = 0{,}55$; $x_{12} = 0{,}6$; $x_{13} = 0{,}65$); the term "High probability" – with the range ($x_{13} = 0{,}65$; $x_{14} = 0{,}7$; $x_{15} = 0{,}75$; $x_{16} = 0{,}8$; $x_{17} = 0{,}85$).

Fuzzy sets $\tilde{C}(\alpha_i), i = \overline{1,4}$ of a fuzzy variable α can be formed on the basis of the expertise statement, which consists in expressing preferences based on the qualitative comparisons, and processing expert data [3, 4]. Qualitative comparisons make it possible to measure the characteristic under consideration of a linguistic variable that has several values. Statement of expertise for the benefit of identifying $\tilde{C}(\alpha_i), i = \overline{1,4}$ is based on the following [2]. For matrix $A = \|a_{ij}\|; i, j = \overline{1,n}$ consideration of the matrix equation $AY^T = \lambda Y$ allows you to determine the corresponding eigenvalues $\lambda_q, q = \overline{1,G}$, as the roots of the characteristic equation $A - \lambda E = 0$, where E – unit matrix. To each eigenvalue $\lambda_q, q = \overline{1,G}$ will match its own vector $Y_g, g = \overline{1,G}$. Matrix equation corresponds to each square *A*

$$AYT{=}\lambda Y, \tag{5}$$

which makes it possible to define its corresponding integers:

$$\lambda_q, \; q = \overline{1, G}, \tag{6}$$

as roots of characteristic equation:

$$A - \lambda E = 0, \tag{7}$$

where E is the identity matrix. Eigenvectors Y_g complies with each town number λq. If we have for matrix *A*:

$$a_{ij} > 0;\, a_{ji} = 1/a_{ij};\, a_{ik} = a_{ij} a_{jk};\, i,\, j,\, k = \overline{1,n}, \tag{8}$$

that is, matrix *A* is integral, inversely symmetrical and coordinated, then equation:

$$A - \lambda E = 0, \tag{9}$$

have one root:

$$\lambda = \lambda_{\max} = n. \tag{10}$$

It is matched with only one own vector *Y*. Therefore, if the subjective opinions of experts regarding $\tilde{C}(a_i) = \{\mu_{\tilde{C}(a_i)}(x)/x\}, x \in X, i = \overline{1,n}$ will expressed by a positive, inverse symmetric, and consistent matrix, then solving the equation $AY^T = nY$ allows us to determine $Y = \{\mu_{\tilde{C}(a)}(x)\}$ vector, and measure of coincidence $\lambda_{\max}$ with *n* will be a measure of the expert judgments coherence.

Each *l* expert $l = \overline{1,L}$ makes a judgment, how many times the value of membership function, for example, value α_1 of fuzzy variable α, $\mu_{\tilde{C}(\alpha_1)}(x_i)$ exceeds the value of membership function $\mu_{\tilde{C}(\alpha_1)}(x_j)$, where $x_i, x_j \in X; \; i, j = \overline{1,n}$.

If $a_{ij}^{(l)} = \dfrac{\mu_{\tilde{C}(\alpha_j)}(x_i)}{\mu_{\tilde{C}(\alpha_j)}(x_j)}$, $a_{ij}^{(l)} = \dfrac{1}{a_{ij}^{(l)}}$, $a_{ik}^{(l)} = a_{ij}^{(l)} \cdot a_{jk}^{(l)}$, then $a_{ij}^{(l)} > 0; \; a_{ij}^{(l)} = 1; \; i, j = \overline{1,n}$. Subjective opinions of experts are averaged, and then $a_{ij} = \dfrac{\sum_{l=1}^{L} a_{ij}^{(l)} \cdot k_l}{\sum_{l=1}^{L} k_l}$, provided that $\sum_{i=1}^{n} \mu_{\tilde{C}(\alpha_1)}(x_i) = 1$, equals

$$K_j = \sum_{i=1}^{n} \frac{\mu_{\tilde{C}(\alpha_1)}(x_i)}{\mu_{\tilde{C}(\alpha_1)}(x_j)} = \frac{1}{\mu_{\tilde{C}(\alpha_1)}(x_j)}, \quad (11)$$

Then by equation

$$A\mu^T = \lambda_{\max}\mu \quad (12)$$

Vector $\mu = \{\mu_{\tilde{C}(\alpha_1)}(x_j)\}, \; j = \overline{1,n}$, where $\{\mu_{\tilde{C}(\alpha_1)}(x_j)\} = \dfrac{1}{k_j}$ is formed. In the general case, obtained from the results of examination processing, the vector μ may not satisfy the equation $AY^T = nY$, for the consistency of a positive inverse symmetric matrix meets the requirement $\lambda_{\max} = n$. Inequation $\lambda_{\max} \geq n$ is always correct. Deviation from consistency can be estimated by the ratio

$$\eta = \frac{\tilde{\lambda}_{\max} - n}{n - 1}, \quad (13)$$

because when comparing n elements, the expert expresses ($n-1$) judgments. Vector $\bar{\lambda}_{\max}$ is the best one from the point of view of element division of vector $A\mu^T$ by vector μ, a $\tilde{\lambda}_{\max}$ – averaged value of $\bar{\lambda}_{\max}$ vector components. If η does not meet accuracy requirements, then matrix A corrects through the obtained μ vector. The iterative procedure is repeated until it satisfies the accuracy requirements at the k-th step.

An expert makes his/her judgments regarding the value of membership function $\mu_{\tilde{C}(\alpha_1)}(x_i)$ exceeds the value of membership function $\mu_{\tilde{C}(\alpha_1)}(x_j)$ each l on the basis of qualitative assessment [5-8]. Under conditions of non-stochastic uncertainty, the use of methods in which the expert makes fuzzy judgments allows the decision maker to "trust" the results to a greater extent, since the expert is relieved of the need to talk about the exact values of the studied parameters.

A matrix for α_1 values as an average result of experts' L opinions based on qualitative binary comparisons in accordance with [2] has the following form (14). Zeros correspond to incomparability of elements for the accepted value of the α_1 variable. Accordingly (11), (12).

$$\begin{bmatrix} 1 & 2 & 3 & 5 & 9 \\ 0,5 & 1 & 1 & 5 & 7 \\ 0,33 & 1 & 1 & 2 & 3 \\ 0,2 & 0,2 & 0,5 & 1 & 2 \\ 0,11 & 0,14 & 0,33 & 0,5 & 1 \end{bmatrix} \cdot \begin{bmatrix} 0,47 \\ 0,23 \\ 0,17 \\ 0,07 \\ 0,045 \end{bmatrix} = \\ = \lambda_{\max}(0,47; 0,23; 0,17; 0,07; 0,045)$$

Obtained μ vector doesn't meet accuracy requirements (13). After the second operation A matrix becomes:

$$A = \begin{bmatrix} 1 & 2,04 & 2,76 & 6,71 & 10,44 \\ 0,49 & 1 & 1,35 & 3,29 & 5,1 \\ 0,36 & 0,74 & 1 & 2,43 & 3,77 \\ 0,15 & 0,304 & 0,412 & 1 & 1,56 \\ 0,096 & 0,196 & 0,265 & 0,641 & 1 \end{bmatrix},$$

and the corrected vector $\mu = (0,477; 0,233; 0,173; 0,071; 0,046)$ meets accuracy requirements.

After normalizing the vector, the fuzzy set of the fuzzy variable (term element) takes the form

$$\tilde{C}(\alpha_1) = (1/3; 0,49/8; 0,36/13; 0,15/18; 0,1/25).$$

A similar setting of the examination and processing of expert data for the formation of fuzzy sets of the remaining fuzzy variables give the following results:

$$\tilde{C}(\alpha_2) = (0,1/24;\ 0,4/28;\ 1/30;\ 0,9/33;\ 0,44/38);$$

$$\tilde{C}(\alpha_3) = (0,32/48;\ 0,44/50;\ 0,81/58;\ 1/60;\ 0,49/73);$$

$$\tilde{C}(\alpha_4) = (0,31/93;\ 0,56/103;\ 0,8/113;\ 1/120;\ 0,45/43).$$

A graphical representation of the obtained fuzzy sets $\tilde{C}(\alpha_1), \tilde{C}(\alpha_2), \tilde{C}(\alpha_3), \tilde{C}(\alpha_4)$ is shown in Figure 1.

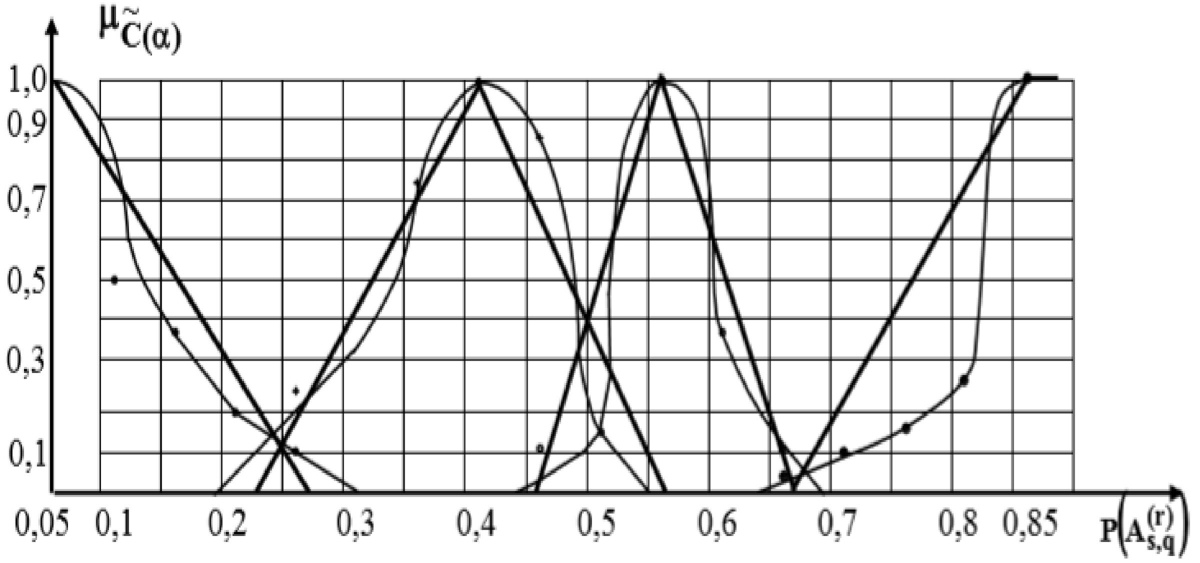

Fig. 1. Graphical representation of the membership function of a linguistic variable

To make a decision, the membership function levels $\mu_{\tilde{C}(\alpha)} \geq 0,5$ can be recommended and the decision maker can focus on the values $P(A_{s,q}^{(r)})$ at the accepted terms for the linguistic variable in question.

		x_1	x_2	x_3	x_4	x_5	x_7	x_8	x_9	…	x_{16}	x_{17}
	x_1	1	2	3	5	9	0	0	0	…	0	0
	x_2	0,5	1	1	5	7	0	0	0	…	0	0
	x_3	0,33	1	1	2	3	0	0	0	…	0	0
	x_4	0,2	0,2	0,5	1	2	0	0	0	…	0	0
A=	x_5	0,11	0,14	0,33	0,5	1	0	0	0	…	0	0
	x_7	0	0	0	0	0	1	0	0	…	0	0
	x_8	0	0	0	0	0	0	1	0	…	0	0
	x_9	0	0	0	0	0	0	0	1	…	0	0
	…	…	…	…	…	…	…	…	…	…	…	…
	x_{16}	0	0	0	0	0	0	0	0	…	1	0
	x_{17}	0	0	0	0	0	0	0	0	…	0	1

Thus, the problem of evaluating a numerical measure of information risk when making decisions in conditions of non-stochastic uncertainty has been solved. the use of a linguistic variable is based on the processing of expert data, presented in the form of a matrix of binary relations of the membership function values, which allows us to proceed to further processing of knowledge to support decision-making in the management of production, commercial, financial and other activities.

Conclusion

As a mathematical model for assessing a numerical measure of information risk when making decisions based on the information obtained under conditions of non-stochastic uncertainty, a model is defined that allows modeling uncertainties of the natural language, which differs from existing ones by formalizing knowledge taking into account the non-stochastic uncertainty of the initial information using fuzzy subsets.

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