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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

DEVELOPMENT OF METHODS AND MODELS FOR EFFECTIVE COST MANAGEMENT WITH REGARD TO SUPPORT AND MAINTENANCE OF INVESTMENT PROJECTS WITHIN THE FRAMEWORK OF FAO UN

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GENERAL DESCRIPTION OF THE DISSERTATION

Relevance of the topic. The 2014–2017 FAO Strategic Framework and Medium Term Plan sets out global trends and key challenges in terms of food and agriculture, which imply a significant increase in food demand, protracted food insecurity, malnutrition, including the continuing spread of obesity among the population, rural poverty, the complexity of agricultural and food production systems, more dynamic flows in the trade in agricultural goods and changing rules for their regulation, climate change, as well as the need for better management in the face of increasing complexity of the agricultural development process.

Currently, FAO is implementing institutional measures aimed at completing the transition from formulating results based on an approach involving the use of the so-called static matrix to a more strategic approach based on "*management aimed at achieving concrete results*". According to this approach, it becomes possible to focus the efforts around the actions necessary to achieve the desired results at all levels, which, in turn, requires the availability of scientific foundations for managing performance, results reporting and using the information to improve decision making.

The basis for FAO performance management can be a model (and subsequently a system) for a comprehensive assessment of intermediate (tactical), strategic and global decisions in the field of safety management, the components of which should be tentative FAO results. Therefore, in order to improve the monitoring of results and relevant reporting, there is a need to create a system for determining and comprehensively evaluating indicators for FAO strategic goals (development results), organizational results and conclusions. Based on this premise, the importance and relevance of the study of methods and models of effective cost management with regard to the support and maintenance of investment projects within the framework of the FAO UN become apparent.

The main aim. The main steps towards creating a monitoring and evaluation system for FAO results and reports are: anticipation, prevention, localization and elimination of incorrect decisions. Moreover,

the determination and evaluation of indicators of strategic goals, organizational results and conclusions, as a rule, is relative, and the temptation to quantify them by averaging is not permissible in terms of the adequacy of the desired results. Therefore, with an integrated assessment of the results and reports, a numerical description (or averaging) of composite indicators is completely unacceptable. Based on these considerations, the main goal of the dissertation is to develop an integrated system for monitoring the FAO results and reports, which is based on a fuzzy cognitive model that reflects a set of critically significant interconnected and/or interdependent components, elements.

The subject of research. The main subject of the research carried out as part of the dissertation is the mechanisms for effective cost management with regard to the support and maintenance of investment projects within the FAO.

Research methods. The methodology of this study is based on the methods of managerial technologies using artificial intelligence elements, including fuzzy logic and cognitive modeling methods, which have proven themselves in the management of ill-structured systems of a humanistic type. In particular, the use of fuzzy logic methods in the management of cognitive systems makes it easy to take into account many parameters for making informed decisions and does not require complex mathematical calculations. Moreover, the mathematical apparatus of the fuzzy set theory makes it equally easy to operate with both structured (quantitative) and ill-structured (qualitative) categories.

In the dissertation, a systematic approach is applied, which allows consolidating processes that are different in nature. As part of this approach, cognitive modeling is used as one of the most appropriate tools for describing and researching ill-structured systems, which, of course, is the FAO results and reports monitoring system. At the same time, the main advantage of the mathematical apparatus of cognitive analysis is the flexibility of cognitive models and their relatively quick adaptability to environmental transformations.

Scientific novelty. The following developments are the basis of the scientific novelty of the dissertation:

- the model of a financial mechanism for effective cost recovery with regard to supporting FAO projects, based on the principle of proportionality;
- a fuzzy cognitive model for assessing the level of food security (FS) for countries (regions) with no guaranteed regular access of the population to high-quality food;
- methods and algorithms for assessing the level of FS for regions within the framework of the FAO Partnership Program;
- an integrated FAO results and reports monitoring system;
- an integrated system of fuzzy models for assessing the factors that form the basis for the FAO Strategic Objectives (SO).

Main results put forward for defense:

- ❑ within the framework of the classification of expenses stipulated by the new concept of the financial mechanism for reimbursement of expenses of the FAO UN, a model of the financial mechanism of effective reimbursement of expenses with regard to supporting FAO projects based on the principle of proportionality has been developed;
- ❑ a fuzzy model for assessing the balance of the budgets of FAO projects for their compliance with the new FAO financial policy in the field of expenditures has been developed and tested;
- ❑ a typical fuzzy cognitive model for assessing the level of FS for countries (regions) with no guaranteed regular access of the population to high-quality food has been developed and described;
- ❑ based on a fuzzy cognitive map, an approach has been formulated and justified for assessing the level of FS for the regions within the framework of the FAO Partnership Program;
- ❑ on the basis of a fuzzy cognitive map, the concept of an integrated for the FAO results and reports monitoring system has been formulated;
- ❑ a fuzzy cognitive model has been developed that reflects a set of critically significant interrelated and/or interdependent factors affecting FS in the regions;
- ❑ an integrated system of fuzzy models for assessing the factors that form the basis for SO approved in the FAO Strategic Framework for 2014-2017 has been developed and tested.

Applicant's personal contribution. The listed main results put by the applicant for the defense of this dissertation have been obtained by the applicant personally.

Theoretical and practical significance. The numerical assessments of specific levels of FS in regions (countries) for their compliance with the FAO SO principles obtained on specific examples allowed formulating a methodology that significantly increases the degree of objectivity of the final results relative to the health care safety level for countries with limited or poor regular access to high-quality food required for an active and healthy lifestyle. Despite the fact that the typical models proposed in this study require structural and parametric optimization in order to claim the necessary degree of adequacy to the task, the proposed approach is in a certain sense flexible in terms of possible additions and/or refinements that may be presented by FAO experts. The developed system of integrated fuzzy models, without giving absolute values for assessing the regional level of public safety, is capable of responding to possible changes in impact factors and ensuring the integrity, consistency and synergy of activities carried out with the support of individual programs, projects and countries, in accordance with the FAO SO.

Practical results of the research. The fuzzy models developed in the dissertation have been tested on specific examples of FAO projects, and the approach to the development of an integrated FAO results and reports monitoring system based on the use of a fuzzy cognitive model has been approved by the FAO expert community.

Validation of the research. The main results of the dissertation have been presented at the 9th International Conference on Theory and Application of Soft Computing, Computing with Words and Perception ICSCCW (Budapest, Hungary, 24–25 August 2017), ICAFS – the 13th International Conference on Application of Fuzzy Systems and Soft Computing (Warsaw, Poland, 27–28 August 2018) with international scientific citation indices from the Web of Science and SCOPUS archives, as well as at seminars of the Signal Recognition Methods and Technical Diagnostic Systems Laboratory and ICS ANAS seminars.

Publications. Based on the results of the research, 14 papers have been published, 10 of which abroad.

The dissertation work is performed at the Institute of Control Systems of ANAS.

Structure and volume of work. The dissertation consists of introduction, four chapters, results and a list of 66 literary sources. Without the table, figures and the list of the literatures the volume of the main content of the dissertation consists of 207000 characters, including: introduction - 12401 characters, Chapter I - 33106 characters, Chapter II - 50477 characters, Chapter III – 60640 characters, Chapter IV - 48909, Results - 1467 characters.

THE CONTENT OF THE DISSERTATION

The introduction of the dissertation states the relevance of the study, provides the full list of the set objectives required to achieve the aim of the dissertation, describes the structure and scope of the dissertation, as well as the desired results put forward for defense.

The first chapter devoted to the analysis of effective accountability and internal control mechanisms of FAO proposes a new concept for the FAO cost recovery mechanism. It is noted that this concept represents a transition from the principles of cost classification and reimbursement of additional costs applied in accordance with the current FAO policy regarding project support costs to the procedure of full proportional cost reimbursement, within which all the costs of ensuring the implementation of the work program for all funding sources are divided into three categories of expenses: direct operating expenses; direct support costs; and indirect support costs. Within the framework of this cost classification, a model of a financial mechanism for the efficient cost reimbursement with regard to supporting FAO projects based on the principle of proportionality is developed.

As a result of the conducted preliminary analysis, the statement of the research objective is formulated, namely, the need to eliminate the existing shortcomings in the FAO internal control system, which are caused by the lack of internal potential in terms of assessment for an early solution to the problem before it becomes serious. It is planned to implement the function of rapid assessment of the results of FAO activities in order to study, evaluate, diagnose and normalize identified

or potential situations in which the proper quality of FAO performance is not ensured.

In the second chapter, the following fuzzy model is proposed and tested to assess the balanced budgets of FAO projects for their compliance with the new FAO financial policy. FAO's new strategic framework program presents new cost proposals under the Programme of Work and Budget (PWB). In particular, Table 1 summarizes the data for resource requirements by strategic/functional objectives (budget chapters), funding sources: net appropriations and extra budgetary contributions.

Table 1. FAO budget proposals

Chapter	Strategic/Functional Objectives	(USD thousands, 2012-2013 exchange rate)						
		NA	(%)	CVC	(%)	Other EC	(%)	Total
01	Contribute to the eradication of hunger, food insecurity and malnutrition	92675	9.12	19944	12.10	132815	10.44	245435
02	Increase and improve provision of goods and services from agriculture, forestry and fisheries in a sustainable manner	193030	19.01	75262	45.65	195898	15.39	464190
03	Reduce rural poverty	64870	6.39	5498	3.34	48952	3.85	119320
04	Enable more inclusive and efficient agricultural and food systems at local, national and international levels	112017	11.03	47943	29.08	82902	6.51	242863
05	Increase the resilience of livelihoods to threats and crises	36617	3.61	7426	4.50	787861	61.91	831904
06	Technical quality, knowledge and services	51587	5.08	58	0.04	34	0.00	51679
07	Technical Cooperation Program	131853	12.98	0	0.00	0	0.00	131853
08	Outreach	66396	6.54	159	0.10	1286	0.10	67841
09	Information Technology	44108	4.34	4	0.00	0	0.00	44112
10	FAO governance, oversight and direction	86249	8.49	1170	0.71	22691	1.78	110110
11	Efficient and effective administration	88596	8.72	7210	4.37	68	0.01	95873
12	Contingencies	600	0.06	0	0.00	0	0.00	600
13	Capital Expenditure	22232	2.19	0	0.00	0	0.00	22232
14	Security Expenditure	24809	2.44	181	0.11	0	0.00	24990
Total Appropriation		1015639	100	164856	100	1272507	100	2453002

For the evaluation of a FAO project in terms of budget balance, it is proposed to use a fuzzy inference mechanism that will establish causal relationships between the characteristics of the budget, on the one hand, and, in fact, the cost allocation structure for its compliance with the new FAO financial policy, on the other. The following fairly simple consistent statements have been taken as the basis:

e_1: "If the appropriations for contributing to the eradication of hunger, food insecurity and malnutrition are within the norm, and the appropriations aimed at increasing and improving provision of goods and services from agriculture, forestry and fisheries in a sustainable manner are within the norm, and the appropriations for the provision of technical quality, knowledge and services are within the norm, and the appropriations aimed at outreach are within the norm, and the appropriations for FAO governance, oversight and direction are within the norm, and the appropriations for the effective and efficient administration are within the norm, then the project budget is balanced";

e_2: "If, in addition to the above requirements, provisions are made to reduce rural poverty within the norm, and the appropriations for the use of information technology are within the norm, and the appropriations for capital expenditure are within the norm, then the project budget is more than balanced";

e_3: "If, in addition to the conditions stipulated in e_2, the appropriations to enable more inclusive and efficient agricultural and food systems at local, national and international levels are within the norm, and the appropriations to increase the resilience of livelihoods to threats and crises are within the norm, and the appropriations for the technical cooperation program are within the norm, and the appropriations for contingencies are within the norm, and the appropriations for security expenditure are within the norm, then the balance of the project budget is perfect";

e_4: "If, in addition to the conditions stipulated in e_2, the appropriations to enable more inclusive and efficient agricultural and food systems at local, national and international levels are within the norm, and the appropriations for security expenditure are within the norm, then the project budget is very balanced";

e_5: "If the appropriations for contributing to the eradication of hunger, food insecurity and malnutrition are within the norm, and the appropriations to enable more inclusive and efficient agricultural and food systems at local, national and international levels are within the norm, and the appropriations to increase the resilience of livelihoods to threats and crises are within the norm, and the appropriations for technical quality, knowledge and services are within the norm, and the appropriations aimed at outreach are within the norm, and the appropriations for FAO governance, oversight and direction are within the norm, and the appropriations for the effective and efficient administration are within the norm, but the appropriations aimed at increasing and improving provision of goods and services from agriculture, forestry and fisheries in a sustainable manner are not provided, then the project budget is still balanced";

e_6: "If the appropriations for technical quality, knowledge and services are not provided, and the appropriations aimed at outreach are not provided, and the appropriations for FAO governance, oversight and direction are not provided, and the appropriations for the effective and efficient administration are not provided, then the project budget is unbalanced".

A fuzzy interpretation of this model for evaluating FAO projects for their compliance with the FAO financial policies is:
e_1: "If $X=\{0.5575/u_1, 0.8365/u_2, 0.9497/u_3\}$, then $Y=B$";
e_2: "If $X=\{0.5575/u_1, 0.6080/u_2, 0.9142/u_3\}$, then $Y=MB$";
e_3: "If $X=\{0.4894/u_1, 0.2147/u_2, 0.8276/u_3\}$, then $Y=P$";
e_4: "If $X=\{0.5575/u_1, 0.6080/u_2, 0.8590/u_3\}$, then $Y=VB$";
e_5: "If $X=\{0.2520/u_1, 0.0945/u_2, 0.0503/u_3\}$, then $Y=B$";
e_6: "If $X=\{0.1258/u_1, 0.0011/u_2, 0.0000/u_3\}$, then $Y=UB$",
where X and Y are linguistic variables taking their values in the form of corresponding fuzzy term sets. In particular, the terms of the variable Y are described by fuzzy subsets of a discrete universal set $J=\{0; 0.1; \ldots; 1\}$ with membership functions: B=BALANCED, $\mu_B(x)=x$; MB=MORE THAN BALANCED, $\mu_{MB}(x)=x^{1/2}$; P=PERFECT, $\mu_P(x) = 1, \text{if } x = 1 \text{ and } \mu_P(x) = 0, \text{if } x < 1$; VB=VERY BALANCED, $\mu_{VB}(x)=x^2$; UB=UNBALANCED, $\mu_{UB}(x)=1-x$. This model was tested on the example of three randomly selected FAO projects: u_1, u_2 and u_3. As a result, a general solution is obtained in the form of the matrix:

R=	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1
u_1	0,4425	0,4525	0,4825	0,5136	0,5136	0,5136	0,5136	0,5136	0,5136	0,5136	0,8742
u_2	0,1635	0,2635	0,3635	0,4635	0,5520	0,6420	0,7520	0,7853	0,7853	0,7853	0,9989
u_3	0,0503	0,1503	0,1724	0,1724	0,1724	0,1724	0,1724	0,1724	0,1724	0,1724	1,0000

After a defuzzification of the model's fuzzy outputs that interpret the degree of budget balance, FAO projects are ranked: u_3 (0.9210), u_2 (0.7219), u_1 (0.7156).

In the third chapter, a typical fuzzy cognitive model is developed and described for assessing the level of FS for countries (Fig. 1) with no guaranteed regular access of the population to high quality food required for an active and healthy lifestyle. A cognitive map covering a fairly wide range of factors affecting FS approved in the FAO UN Strategic Framework is taken as the basis. At the same time, limited sets of logically based rules are used for the formalization of cause-and-effect relationships between factors affecting FS.

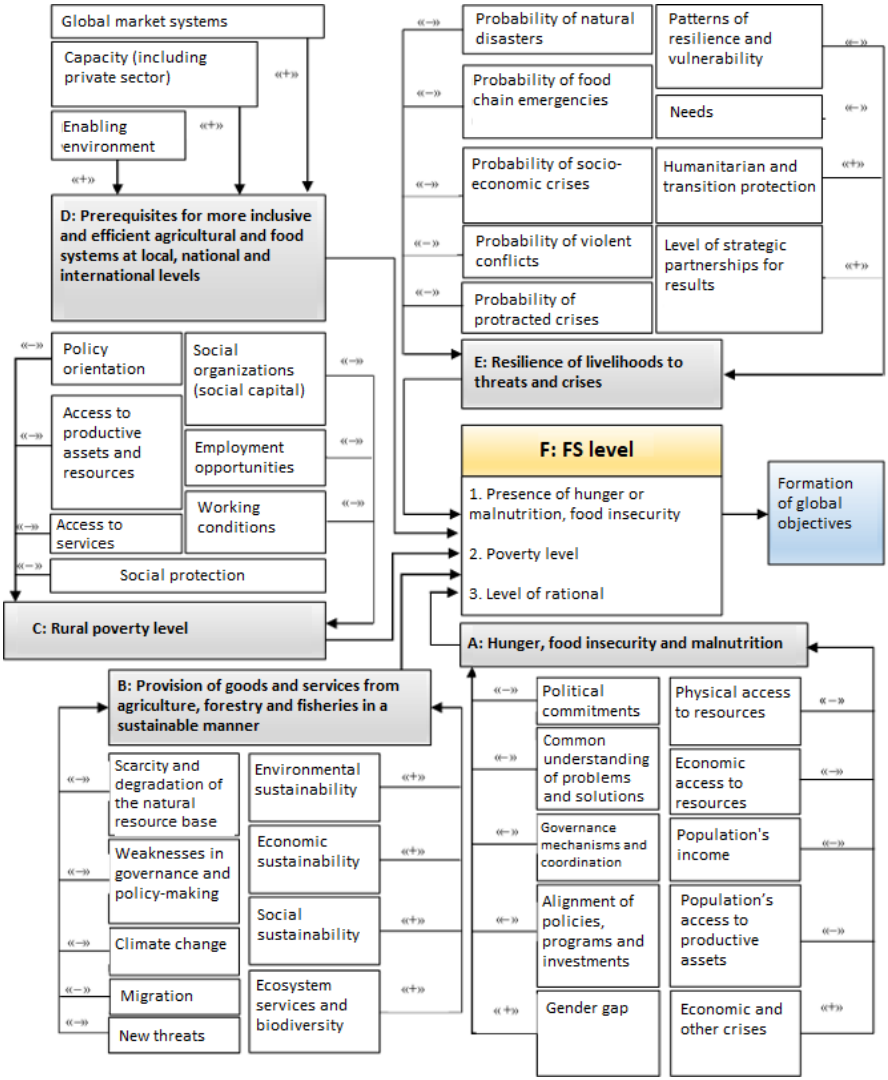

Fig. 1. Fuzzy cognitive map for FS analysis

In particular, for the concept of SO 1: *The level of hunger and poverty*, the cause-and-effect relationships between factors affecting FS were formalized using the following set of judgments:

a_1: “If physical and economic access to resources is unlimited, population incomes are high, access to productive assets is unlimited, economic and other crises are imperceptible, political commitments are observed to a sufficient extent and there is a full understanding of FS problems and solutions, effective governance mechanisms and coordination are used, and the alignment of policies, programs and investments is high, and there is no gender gap, then the problem of hunger and poverty is absolutely non-sensitive”;

a_2: “If physical and economic access to resources is unlimited, population incomes are high, political commitments are observed to a sufficient extent and there is a full understanding of FS problems and solutions, effective governance mechanisms and coordination are used, and the alignment of policies, programs and investments is high, and there is no gender gap, then the problem of hunger and poverty is very non-sensitive”;

a_3: “If physical and economic access to resources is unlimited, political commitments are observed to a sufficient extent and there is a full understanding of FS problems and solutions, effective governance mechanisms and coordination are used, and the alignment of policies, programs and investments is high, then the problem of hunger and poverty is more than non-sensitive”;

a_4: “If physical and economic access to resources is unlimited, population incomes are high, access to productive assets is unlimited, then the problem of hunger and poverty is non-sensitive”;

a_5: “If physical and economic access to resources is limited, population incomes are low, access to productive assets is limited, then the problem of hunger and poverty is sensitive”;

a_6: “If physical and economic access to resources is limited, political commitments are observed to an insufficient extent and there is a weak understanding of FS problems and solutions, ineffective governance mechanisms and coordination are used, and the alignment of policies, programs and investments is low, then the problem of hunger and poverty is more than sensitive”;

a_7: “If physical and economic access to resources is limited, population incomes are low, political commitments are observed to an insufficient extent and there is a weak understanding of FS problems and

solutions, ineffective governance mechanisms and coordination are used, and the alignment of policies, programs and investments is low, and there is notable gender gap, then the problem of hunger and poverty is very sensitive";

a_8: "If physical and economic access to resources is limited, population incomes are low, access to productive assets is limited, economic and other crises are perceptible, political commitments are observed to an insufficient extent and there is a complete lack of understanding of FS problems and solutions, ineffective governance mechanisms and coordination are used, and the alignment of policies, programs and investments is low, and there is notable gender gap, then the problem of hunger and poverty is too sensitive".

To obtain a final assessment of FAO results, namely, to determine the aggregate indicator of the FS level, a fuzzy model based on the following considerations was applied:

r_1: "If the problem of hunger and poverty is sensitive and the process of providing goods and services from agriculture, forestry and fisheries is unsustainable, then the level of FS is low";

r_2: "If, in addition to the above, the prerequisites for the creation of agricultural and food systems are insignificant and the resilience of livelihoods to threats and crises is unstable, then the level of FS is more than low";

r_3: "If, in addition to the conditions stipulated in r_2, it is known that the rural poverty level is high, then the level of FS is too low";

r_4: "If the problem of hunger and poverty is sensitive, rural poverty level is high, the prerequisites for the creation of agricultural and food systems are insignificant and the resilience of livelihoods to threats and crises is unstable, then the level of FS is very low";

r_5: "If the problem of hunger and poverty is sensitive, rural poverty level is high, the prerequisites for the creation of agricultural and food systems are insignificant but the resilience of livelihoods to threats and crises is stable, then the level of FS is still low";

r_6: "If the problem of hunger and poverty is non-sensitive and the process of providing goods and services from agriculture, forestry and fisheries is sustainable, and rural poverty level is low, then the level of FS is high".

In the fourth chapter, an approach to the assessment of the FS level for the regions within the framework of the FAO Partnership Program is proposed. To assess the impact of the factors that form the basis for SO approved in the FAO Strategic Framework for 2014-2017 on FS in the regions, a system of integrated fuzzy models implemented based on a fuzzy inference mechanism is used.

Based on the approach formulated in Chapter III, a software simulation of the process of comprehensive assessment of the FS level was carried out using as an example several regions that underwent preliminary technical analysis and were characterized at the beginning by expert assessments by the factors forming the basis of the FAO SO: SO1 – Hunger, food insecurity and malnutrition; SO2 – Provision of goods and services from agriculture, forestry and fisheries in a sustainable manner; SO3 – Rural poverty level; SO4 – Prerequisites for more inclusive and efficient agricultural and food systems at local, national and international levels; SO5 – Resilience of livelihoods to threats and crises, in the form of the following Table 2.

The reference expert indicators in Table 2 satisfy the requirements: $\sum_{i=1}^{n} w_{ki} e_{ki} \rightarrow \max$, $\sum_{i=1}^{n} w_{ki} = 1$ where n is the number of component factors of impact on the k-th FAO CO basis (k=1÷5); w_{ki} is the value of the weighted coefficient of the i-th factor of the k-th determinant; e_{ki} is the value of the indicator of the consolidated opinion of all experts regarding the i-th factor of the k-th determinant, which is determined by averaging: $e_{ki} = \frac{1}{m}\sum_{j=1}^{m} e_{ki}^{j}$, where m is the number of experts involved; e_{ik}^{j} is the assessment of the i-th factor of the k-th determinant for the FAO strategic objective by the j-th expert. The degree of consistency (W_k) of the opinions of expert groups as a whole on the totality of all factors in the k-th determinant for the FAO strategic objective is determined as follows:

$$W_k = \frac{12}{n^3 - n}\sum_{i=1}^{n}[e_{ik} - \frac{n+1}{2}]^2.$$

Table 2. Preliminary expert evaluation of alternative projects

FAO SO	Factor determining FAO SO	Expert assessments of alternative projects on a 10-point scale				Evaluation criteria (term)
		u_1	u_2	u_3	u_4	
SO1	x_{11} – Physical access to resources	7.76	2.17	8.95	3.24	UNLIMITED
	x_{12} – Economic access to resources	6.67	3.91	2.77	3.48	UNLIMITED

	x_{13} – Population's income	9.29	4.11	9.78	1.00	HIGH
	x_{14} – Population's access to productive assets	4.68	5.73	9.82	4.21	UNLIMITED
	x_{15} – Economic and other crises	0.34	7.74	4.17	9.79	IMPERCEPTIBLE
	x_{16} – Country's political commitments	5.74	2.22	5.83	1.34	SUFFICIENT
	x_{17} – Common understanding of problems and solutions	5.65	7.25	7.15	9.62	FULL
	x_{18} – Governance mechanisms and coordination	0.62	2.54	7.06	1.99	EFFECTIVE
	x_{19} – Alignment of policies, programs and investments	5.05	1.66	7.31	8.59	HIGH
	$x_{1,10}$ – Gender gap	3.33	8.56	0.31	3.96	ABSENT
SO2	x_{21} – Scarcity and degradation of the natural resource base	0.19	1.01	3.21	6.01	IMPERCEPTIBLE
	x_{22} – Ecosystem services and biodiversity	9.94	6.32	4.78	3.56	WIDE
	x_{23} – Climate change	7.81	6.45	6.90	7.22	INSIGNIFICANT
	x_{24} – Migration	6.91	4.01	4.89	8.18	INSUBSTANTIAL
	x_{25} – New threats	5.48	7.71	7.73	3.49	INSUBSTANTIAL
	x_{26} – Weaknesses in governance and policy-making	0.62	4.40	1.38	4.80	ABSENT
	x_{27} – Environmental sustainability	2.91	5.71	6.11	8.83	STRONG
	x_{28} – Economic sustainability	0.49	5.30	9.73	9.54	STRONG
	x_{29} – Social sustainability	6.76	6.39	1.70	2.47	STRONG
SO3	x_{31} – Policy orientation	8.80	6.92	6.00	7.65	TARGETED
	x_{32} – Access to productive assets and resources	5.38	9.52	4.79	3.06	SUFFICIENT
	x_{33} – Access to services	6.05	1.45	7.87	0.78	SUFFICIENT
	x_{34} – Social organizations (social capital)	4.31	4.45	0.41	7.05	STRONG
	x_{35} – Employment opportunities	0.17	4.54	4.49	9.40	LIMITED
	x_{36} – Working conditions	8.17	9.13	1.10	4.48	UNWORTHY
	x_{37} – Social protection	1.97	3.24	4.90	3.44	INSUFFICIENT
SO4	x_{41} – Enabling environment	9.42	8.20	2.23	3.29	SUFFICIENTLY ENABLING
	x_{42} – Capacity (including private sector)	7.86	2.53	3.36	4.95	HIGH
	x_{43} – Global market systems	1.78	3.87	4.41	4.37	PREFERRED
SO5	x_{51} – Probability of natural disasters	8.13	1.07	1.77	8.98	LOW
	x_{52} – Probability of food chain emergencies	1.14	1.88	1.55	7.87	LOW
	x_{53} – Probability of socio-economic crises	9.52	4.88	9.51	4.48	LOW
	x_{54} – Probability of violent conflicts	5.51	5.97	1.60	6.84	LOW
	x_{55} – Probability of protracted crises	1.01	4.38	4.35	2.21	LOW
	x_{56} – Patterns of resilience and vulnerability	2.68	8.55	1.71	6.54	WEAK
	x_{57} – Needs	9.67	9.06	5.88	7.69	SATISFIED
	x_{58} – Humanitarian and transition protection	7.99	9.22	1.55	5.26	STRONG
	x_{59} – Level of strategic partnerships for results	3.83	8.66	3.59	8.98	HIGH

To obtain consolidated assessments of the FS levels in the considered alternative regions u_1, u_2, u_3 and u_4, we shall use the following set of considerations that determine causal relationships between the determinants of FAO SO, on the one hand, and the FS level itself, on the other.

r_1: “If the problem of hunger and poverty is sensitive and the process of providing goods and services from agriculture, forestry and fisheries is unsustainable, then the level of FS is low”;

r_2: “If, in addition to the above, the prerequisites for the creation of agricultural and food systems are insignificant and the resilience of livelihoods to threats and crises is unstable, then the level of FS is more than low”;

r_3: “If, in addition to the conditions stipulated in r_2, it is known that the rural poverty level is high, then the level of FS is too low”;

r_4: “If the problem of hunger and poverty is sensitive, rural poverty level is high, the prerequisites for the creation of agricultural and food systems are insignificant and the resilience of livelihoods to threats and crises is unstable, then the level of FS is very low”;

r_5: “If the problem of hunger and poverty is sensitive, rural poverty level is high, the prerequisites for the creation of agricultural and food systems are insignificant but the resilience of livelihoods to threats and crises is stable, then the level of FS is still low”;

r_6: “If the problem of hunger and poverty is non-sensitive and the process of providing goods and services from agriculture, forestry and fisheries is sustainable, and rural poverty level is low, then the level of FS is high”.

Based on these considerations, a complete set of input and output linguistic variables is formulated and summarized in Table 3. The system of fuzzy inference regarding the level of FS in the region is constructed as follows:

r_1: “If x_1=SENSITIVE and x_2=UNSUSTAINABLE, then y=LOW”;

r_2: “If x_1=SENSITIVE and x_2=UNSUSTAINABLE and x_4=INSIGNIFICANT and x_5=UNSTABLE, then y=MORE THAN LOW”;

r_3: “If x_1=SENSITIVE and x_2=UNSUSTAINABLE and x_3=HIGH and x_4=INSIGNIFICANT and x_5=UNSTABLE, then y=TOO LOW”;

r_4: “If x_1=SENSITIVE and x_3=HIGH and x_4=INSIGNIFICANT and x_5=UNSTABLE, then y=VERY LOW”;

r_5: “If x_1=SENSITIVE and x_3=HIGH and x_4=INSIGNIFICANT and x_5=STABLE, then y=LOW”;

r_6: “If x_1=NON-SENSITIVE and x_2=SUSTAINABLE and x_3=LOW, then y=HIGH”.

Table 3. Variable fuzzy inference systems for assessing FS

Inputs	x_1	Variable name	Problem of hunger and poverty
		Term-set	{NON-SENSITIVE, SENSITIVE}
		Universal set	[0; 1]
	x_2	Variable name	Provision of goods and services from agriculture, forestry and fisheries
		Term-set	{UNSUSTAINABLE, SUSTAINABLE}
		Universal set	[0; 1]
	x_3	Variable name	Rural poverty level
		Term-set	{LOW, HIGH}
		Universal set	[0; 1]
	x_4	Variable name	Prerequisites for more inclusive and efficient agricultural and food systems at local, national and international levels
		Term-set	{INSIGNIFICANT}
		Universal set	[0; 1]
	x_5	Variable name	Resilience of livelihoods to threats and crises
		Term-set	{UNSTABLE, STABLE}
		Universal set	[0; 1]
Output y		Variable name	Level of food security in the region
		Term-set	{TOO LOW, VERY LOW, MORE THAN LOW, LOW, HIGH}
		Universal set	[0; 1]

The fuzzification of terms from the left-hand sides of the rules is carried out on the discrete universal set $\{u_1, u_2, u_3, u_4\}$ using the membership function $\mu_{A_{ki}}(u_t) = \exp\{-[e_{ki}(u_t) - 10]^2 / \sigma_{ki}^2\}$, where $e_{ki}(u_t)$ is the consolidated expert assessment of the region u_t (t=1÷4) for compliance with the assessment criterion for the i-th factor of the k-th FAO SO determinant; σ_{ki}^2=121 is the distribution density of the nearest elements selected as uniform for all cases. Then, for the left-hand terms of the rules, the following is obtained:

x_1 – SENSITIVE: A_1={0.4275/u_1; 0.2266/u_2; 0.4459/u_3; 0.1675/u_4};

x_2 – UNSUSTAINABLE: A_2={0.4522/u_1; 0.2060/u_2; 0.3205/u_3; 0.4205/u_4};

x_3 – HIGH: A_3={0.3938/u_1; 0.4500/u_2; 0.2443/u_3; 0.3283/u_4};

x_4 – INSIGNIFICANT: A_4={0.2669/u_1; 0.4113/u_2; 0.4450/u_3; 0.4422/u_4};

x_5 – UNSTABLE: A_5={0.4508/u_1; 0.2419/u_2; 0.2360/u_3; 0.4510/u_4}.

For the terms of the output variable y that reflects the general level of FS in the region, fuzzy subsets of the discrete universal set J={0; 0,1; …; 1} are constructed with corresponding membership functions $\forall j \in J$: TL=TOO LOW: μ_{TL}=0, if j=1 and μ_{TL}=1, if j<1; VL=VERY LOW:

$\mu_{VL}(j)=(1-j)^2$; ML=MORE THAN LOW: $\mu_{ML}=(1-j)^{1/2}$; L=LOW: $\mu_{IS}(j)=1-j$; H=HIGH: $\mu_H(j)=j$.

Taking into account the introduced formalisms, the rules are written as follows:

r_1: "If $x_1=A_1$ and $x_2=A_2$, then $y=L$";

r_2: "If $x_1=A_1$ and $x_2=A_2$ and $x_4=A_4$ and $x_5=A_5$, then $y=ML$";

r_3: "If $x_1=A_1$ and $x_2=A_2$ and $x_3=A_3$ and $x_4=A_4$ and $x_5=A_5$, then $y=TL$";

r_4: "If $x_1=A_1$ and $x_3=A_3$ and $x_4=A_4$ and $x_5=A_5$, then $y=VL$";

r_5: "If $x_1=A_1$ and $x_3=A_3$ and $x_4=A_4$ and $x_5=\neg A_5$, then $y=L$";

r_6: "If $x_1=\neg A_1$ and $x_2=\neg A_2$ and $x_3=\neg A_3$, then $y=H$".

After finding membership functions for the left-hand sides of the rules by the principle of minimum, the rules were presented in a more compact form:

r_1: "If $x=M_1$, then $y=L$"; r_2: "If $x=M_2$, then $y=ML$";

r_3: "If $x=M_3$, then $y=TL$"; r_4: "If $x=M_4$, then $y=VL$";

r_5: "If $x=M_5$, then $y=L$"; r_6: "If $x=M_6$, then $y=H$",

where:

$$M_1=\frac{0.4275}{u_1}+\frac{0.206}{u_2}+\frac{0.321}{u_3}+\frac{0.167}{u_4};\quad M_2=\frac{0.2669}{u_1}+\frac{0.206}{u_2}+\frac{0.236}{u_3}+\frac{0.167}{u_4};$$

$$M_3=\frac{0.2669}{u_1}+\frac{0.206}{u_2}+\frac{0.236}{u_3}+\frac{0.167}{u_4};\quad M_4=\frac{0.2669}{u_1}+\frac{0.2266}{u_2}+\frac{0.236}{u_3}+\frac{0.167}{u_4};$$

$$M_5=\frac{0.2669}{u_1}+\frac{0.2266}{u_2}+\frac{0.2443}{u_3}+\frac{0.167}{u_4};$$

$$M_6=\frac{0.5478}{u_1}+\frac{0.55}{u_2}+\frac{0.5541}{u_3}+\frac{0.5795}{u_4}.$$

After converting these rules using the Lukasiewicz implication: $\mu_H(w,i)=\min\{1, 1-\mu_A(w)+\mu_B(i)\}$, where H is the fuzzy subset on $W\times I$ ($w\in W$, $i\in I$), the corresponding fuzzy relations were obtained, the intersection of which eventually gave a general functional solution, reflecting the causal relationship between the FAO SO determinants and the level of FS in the region in the form of the following matrix:

$$R=\left[\begin{array}{c|cccccccccc} & 0 & 0.1 & 0.2 & 0.3 & 0.4 & 0.5 & 0.6 & 0.7 & 0.8 & 0.9 & 1 \\ \hline u_1 & 0.4522 & 0.5522 & 0.6522 & 0.7522 & 0.8522 & 0.9522 & 0.8931 & 0.8231 & 0.7725 & 0.6725 & 0.5725 \\ u_2 & 0.4500 & 0.5500 & 0.6500 & 0.7500 & 0.8500 & 0.9500 & 0.9334 & 0.8634 & 0.8134 & 0.7834 & 0.7734 \\ u_3 & 0.4459 & 0.5459 & 0.6459 & 0.7459 & 0.8459 & 0.9459 & 0.9240 & 0.8540 & 0.8040 & 0.7740 & 0.6795 \\ u_4 & 0.4205 & 0.5205 & 0.6205 & 0.7205 & 0.8205 & 0.9205 & 0.9930 & 0.9230 & 0.8730 & 0.8430 & 0.8330 \end{array}\right]$$

The fuzzy inference regarding the level of FS in the region u_k is reflected in the form of the fuzzy subset E_k of the discrete universal set U={0; 0.1; 0.2; …; 1} with the corresponding values of the membership function from the k-th row of the matrix R. To numerically evaluate these inferences, the following defuzzification procedure is used. In particular, for the FS level in the region u_1, which is interpreted as:

$$E_1=\frac{0.4522}{0}+\frac{0.5522}{0.1}+\frac{0.6522}{0.2}+\frac{0.7522}{0.3}+\frac{0.8522}{0.4}+\frac{0.9522}{0.5}+\frac{0.8931}{0.6}+\frac{0.8231}{0.7}+\frac{0.7725}{0.8}+\frac{0.6725}{0.9}+\frac{0,5725}{1.0},$$

establishing level sets $E_{1\alpha}$ ($\alpha\in[0; 1]$) and calculating the corresponding powers $M(E_{1\alpha})$:

- for $0<\alpha<0.4522$: $\Delta\alpha=0.4522$, $E_{1\alpha}$={0; 0.1; 0.2; …; 0.9; 1}, $M(E_{1\alpha})=0.50$;
- for $0.4522<\alpha<0.5522$: $\Delta\alpha=0.1$, $E_{1\alpha}$={0.1; 0.2;…; 1}, $M(E_{1\alpha})=0.55$;
- for $0.5522<\alpha<0.5725$: $\Delta\alpha=0.0203$, $E_{1\alpha}$={0.2; 0.3; …; 1}, $M(E_{1\alpha})=0.60$;
- for $0.5725<\alpha<0.6522$: $\Delta\alpha=0.0797$, $E_{1\alpha}$={0.2; 0.3; …; 0.9}, $M(E_{1\alpha})=0.55$;
- for $0.6522<\alpha<0.6725$: $\Delta\alpha=0.0203$, $E_{1\alpha}$={0.3; 0.4; …; 0.9}, $M(E_{1\alpha})=0.60$;
- for $0.6725<\alpha<0.7522$: $\Delta\alpha=0.0797$, $E_{1\alpha}$={0.3; 0.4; …; 0.8}, $M(E_{1\alpha})=0.55$;
- for $0.7522<\alpha<0.7725$: $\Delta\alpha=0.0203$, $E_{1\alpha}$={0.4; 0.5; …; 0.8}, $M(E_{1\alpha})=0.60$;
- for $0.7725<\alpha<0.8231$: $\Delta\alpha=0.0505$, $E_{1\alpha}$={0.4; …; 0.7}, $M(E_{1\alpha})=0.55$;
- for $0.8231<\alpha<0.8522$: $\Delta\alpha=0.0291$, $E_{1\alpha}$={0.4; 0.5; 0.6}, $M(E_{1\alpha})=0.50$;
- for $0.8522<\alpha<0.8931$: $\Delta\alpha=0.0409$, $E_{1\alpha}$={0.5; 0.6}, $M(E_{1\alpha})=0.55$;
- for $0.8931<\alpha<0.9522$: $\Delta\alpha=0.0591$, $E_{1\alpha}$={0.5}., $M(E_{1\alpha})=0.50$.

the numerical estimate obtained as follows:

$$F(E_1)=\frac{1}{0.9522}\int_0^{0.9522} M(E_{1\alpha})d\alpha=[0.5\cdot 0.4522+0.55\cdot 0.1+0.60\cdot 0.0203+$$
$$+0.55\cdot 0.0797+0.60\cdot 0.0203+0.55\cdot 0.0797+0.60\cdot 0.0203+0.55\cdot 0.0505+$$
$$+0.50\cdot 0.0291+0.55\cdot 0.0409+0.5\cdot 0.0591]=0.5248.$$

The point estimates of fuzzy inferences regarding the levels of FS for other regions are established in a similar manner: u_2 – $F(E_2)$=0.5482; u_3 – $F(E_3)$=0.5426; u_4 – $F(E_4)$=0.5723. According to these calculations, the region u4 received the highest rating with a value of 0.5723. Further in descending order: $u_2 \rightarrow 0.5482$, $u_3 \rightarrow 0.5426$ and $u_1 \rightarrow 0.5248$.

Thus, numerical estimates of FS levels in the regions have been obtained, taking into account their compliance with the determinants of the FAO SO, both regions and preliminary expert assessments being selected arbitrarily. Nevertheless, the proposed assessment method significantly increases the degree of objectivity of the final results regarding to the FS level for countries with limited or insufficiently guaranteed regular access of the population to high-quality food required for an active and healthy lifestyle. For a more adequate description of terms from the rules, it is necessary to conduct preliminary studies related to collecting relevant data from subject areas and conducting statistical analysis, including preliminary expert assessments of the factors of impact on the FAO SO determinants in order to form universal sets for constructing adequate fuzzy sets. This is perhaps the most complex and time-consuming process, the implementation of which requires access to FAO databases.

MAIN RESULTS

The main scientific results put forward for defense have been formulated as the following statements:

- within the framework of the classification of expenses stipulated by the new concept of the financial mechanism for reimbursement of expenses of the FAO UN, a model of the financial mechanism of effective reimbursement of expenses with regard to supporting

FAO projects based on the principle of proportionality has been developed;

- a fuzzy model for assessing the balance of the budgets of FAO projects for their compliance with the new FAO financial policy in the field of expenditures has been developed and tested;
- a typical fuzzy cognitive model for assessing the level of FS for countries (regions) with no guaranteed regular access of the population to high-quality food has been developed and described;
- based on a fuzzy cognitive map, an approach has been formulated and justified for assessing the level of FS for the regions within the framework of the FAO Partnership Program;
- on the basis of a fuzzy cognitive map, the concept of an integrated for the FAO results and reports monitoring system has been formulated;
- a fuzzy cognitive model has been developed that reflects a set of critically significant interrelated and/or interdependent factors affecting FS in the regions;
- an integrated system of fuzzy models for assessing the factors that form the basis for SO approved in the FAO Strategic Framework for 2014-2017 has been developed and tested.

The main results of the dissertation have been published in the following research papers:

1. Алиев Э.Т. Механизм подотчётности и внутреннего контроля / Рим, 11-15 ноября 2013 года. [Электронный ресурс]. – Режим доступа: http://www.fao.org/docrep/meeting/029/mi800R.pdf
2. Алиев Э.Т. Новая стратегическая рамочная программа FAO UN / Рованиеми, 9-13 декабря 2013 года. [Электронный ресурс]. – Режим доступа: http://www.fao.org/docrep/meeting/029/mi558r.pdf
3. Алиев Э.Т. Всеобъемлющий финансовый механизм возмещения расходов – обновлённая информация / Рим, 26-30 мая 2014 года. [Электронный ресурс]. – Режим доступа: http://www.fao.org/docrep/meeting/030/mk329r.pdf
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7. Алиев Э.Т. Мониторинг результатов и отчётностей FAO UN на основе применения нечёткой когнитивной модели // Математические Машины и Системы, Киев, 2016, №2, стр. 56-71.
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15. Алиев Э.Т. Годовой отчёт о вспомогательных расходах и их возмещении / Рим, 12–16 ноября 2018 года. [Электронный ресурс]. – Режим доступа: http://www.fao.org/fileadmin/user_upload/bodies/Fin_Comm/FC_173-Documents/FC_173-06/FC173-6-MY236-R.pdf.
16. Aliyev E.T. Recovering costs [Электронный ресурс]. – Режим доступа: Intranet.FAO.org detail: Recovering costs.

Applicant's personal contribution to the publications:

[1] Development of a financial mechanism for effective cost recovery in accordance with the FAO Framework for Investment Project Support.

[2] Development of a typical cognitive map and its adaptation.

[4] Development of a fuzzy cognitive model for an integrated assessment of food security based on the results of FAO reporting and a de-

scription of cause-and-effect relationships between the factors impacting the determinants of FAO SO and the level of FS in the region under consideration.
[5] Development and testing of a fuzzy model for assessing the balance of costs provided for by investment projects for their compliance with the FAO New Framework Program.
[6] Development of methods and algorithms for evaluating investment projects for compliance of their stipulated expenses with the FAO New Framework Program.
[7] Construction and analysis of an integrated system of fuzzy models as part of the achievement of the FAO SO for the operational assessment of FS in the region as part of the FAO cooperation program.
[9] Development of a fuzzy inference system for assessing food security in the regions as part of the FAO UN Cooperation Program.
[10] Compilation of expert knowledge through a fuzzy inference system

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