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Cognitive mapping concept of the resource management for the viability of local communities

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ABSTRACT

The local community is a complex socio-economic system, and its ability to function for an indefinitely long period of time (viability) is not investigated sufficiently today. The purpose of the research was, using the cognitive mapping, propose to the local community management developing their own management strategies to ensure its viability. Considering the weakly structured subject area of resource management for the viability of the local community and the complex dynamic nature of socio-economic processes, fuzzy cognitive reflection was suggested as a tool that provides opportunities for modeling the inherent complexity and uncertainty associated with socio-economic systems. This research shows a system of relations between concepts in the form of a causative network – a cognitive map of the resource management of a local community and proposes scales for measuring the concepts. During the simulation experiments, managed, indirectly managed and unmanaged resources for the viability of a local community were defined. In modeling, own income per inhabitant has been chosen as the target concept and as an indicator of the potential of an independent choice of direction for the development of the local community with the view toward the construction of resource management scenarios for the local community's viability. As a result of the simulation, there were proposed some strategies for the growth of 'own income per inhabitant' and some recommendations were given for building management scenarios within these strategies.

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INTRODUCTION

The analysis of the world publications that outline the livelihoods of the local communities has shown that most countries, at present, are aiming to improve the existing system of their functioning. At this time Ukraine is only taking the first steps forward in this direction. Authors viewed local communities from different prospectives. The aspect of the territorial cohesion and the importance of planning in local communities in European integration processes were considered by Alexandru, 2017. The institutional and law aspects of local communities were studied by Bessa, 2015; Heinze *et al.*, 2016; Pronko *et al.*, 2018. An important place in the research take the goal of determining the resources of territorial communities: information (Kim, *et al.*, 2011; Napoli, *et al.*, 2017); innovative (Michelucci and De Marco, 2017); energy (Mckenna, *et al.*, 2018); investment (Di Maddaloni and Davis, 2018); critical to the sustainability of community projects (Aksorn and Charoenngam, 2015); external relationships with the enterprises (Popescu, *et al.*, 2017) and other local communities; financial (Kogut-Jaworska, 2017). The importance of financial resources among other resources was proved in research conducted by Caldas, *et al.*, 2016. The authors focus on "measuring what is important" in local government and emphasize the need to create a new model of assessment, a sustainability index based on the integration of financial indicators of sustainable development and community management. Thus, this can be an important contribution to the creation of a new paradigm for assessing local government and strategic management. All authors are inclined to consider a local community as a complex socio-economic system. Any system should be viable. This is a key integral characteristic that reflects the ability to operate the system for an indefinitely long period of time, but subject to the perturbation factors at an acceptable level of system efficiency. The characteristics of the system that must determine the compliance of the system with the requirements of viability are adaptability, internal balance, equilibrium with the environment, reliability, sensitivity, stability, maneuverability, manageability, hierarchy. At the stage of forming local communities in Ukraine, we believe it is necessary to consider these characteristics for the purpose of achieving viable local communities. The system of resources that should contribute to the socio-economic development of local communities includes natural resources (fuel and energy and mineral raw materials) and economic resources (material, financial, human and intangible), information and infrastructure resources. Economic and mathematical models in the decision-making process concerning the management of local community resources are mostly not used at the moment, which causes the increase of time spent on risk assessment and decision-making, and in addition, subjectivity and insufficient reasoning of decisions. In order to achieve the systematic and continuous process of management of a local community, reducing the time to assess the level of risk and decision-making, improving their quality, it is necessary to develop an economic-mathematical model of resource management for the viability of a local community. In our opinion, the analysis tool capable of realizing the task is cognitive mapping. The methodology of cognitive mapping (Abramova and Kovriga, 2009; Axelrod, 1976; Gray, *et al.*, 2015; Kosko, 1986; Kardaras and Karakostas, 1999) was developed for the study of such complex systems as socio-economic, environmental and political ones, which makes it possible to bring together different approaches, techniques, methods of various disciplines in order to create a system of methods necessary for solving a set of such tasks as:

- Identification of the object in the form of a cognitive model (map);
- Analysis of cycles of the cognitive model;
- Scenario analysis and developing of system development strategies;
- work out the inverse problem of finding management decisions that provide the desired development strategy;
- Solving tasks of realization, observation, manageability, optimization, predictability prognosticability.

The purpose of the study was, using the cognitive mapping, propose to the local community management developing their own management strategies to ensure its viability.

This study has been carried out at the Department of Banking in Oles Gonchar Dnipro National University, Dnipro, Ukraine in 2018.

MATERIALS AND METHODS

The survey was conducted in several stages in accordance with the classical order of cognitive modeling.

Step 1: Identification of factors, selection of research methodology and implementation tools

At this stage, information on the resources for the viability of a local community was provided and summarized, as well as existing approaches to their evaluation and management. There were also made conclusions on the relevance of the in-depth research to determine the most important resources that ensure the viability of a local community. As a hypothesis, the position on manageability of local community resources was put forward. In the analysis, it was determined that decision-making in the management of a local community is complicated due to the weakly structured subject area "Resource management for the viability of a local community", the complex and dynamic nature of socio-economic processes, the presence of a large number of factors that influence the course of such processes, variability of the external environment, the emergence of completely new situations. The simulation modelling in most cases uses quantitative objective assessments. The traditional decision making theory is based on the methods of choosing a better alternative from a set of well-formulated alternatives. Therefore, these methods are not very valid for this research**.** Information based on decisions made in the field of local community management inevitably contains an essential part of qualitative, fuzzy, subjectively evaluated data, and is, in essence, a representation of the expert's (or an expert group) knowledge of a situation that describes the problem area. All these circumstances necessitate the use of the cognitive mapping method for research and resource management for the local community's viability. The method is based on the principles of system analysis of information on socio-economic processes. The main advantage of the proposed approach to cognitive mapping is the possibility of systematic qualitative or mixed (and not only quantitative) accounting of the remote consequences of the decisions taken and the detection of side effects that may impede the implementation of solutions and which are difficult to evaluate intuitively with a large number of existing factors and the diversity of multiple ways of interaction between them. The decision maker often uses qualitative assessments such as "little", "a lot", "very close", "quite a lot", "too slow", and so on. In this situation, it seems logical to use fuzzy concepts and peer reviews in the model of assessment and management. In addition, for the convenience of the user, the dialogue with the model in simulating should also take place using fuzzy categories. Therefore, the choice of an information system for modeling a weakly structured situation is determined by a compromise between accuracy, adequacy of the model of the situation and the time along with the complexity of its creation. Today, the widespread software products that provide the implementation of cognitive methodology are MATLAB, Decision Explorer, Aidos (Lutsenko *et al.*, 2018), Compass (Kulinich, 2014), Kanva (Kulinich, 2014), IGLA (Podvesovskii and Isaev, 2018). For modelling, we have chosen the system of situation analysis and decision-making support based on the cognitive maps "Kanva" (hereinafter Kanva system), the advantages of which are the possibility of taking into account the current state of the management object, adjusting the weight of the connection between factors, conducting additional expert procedures in order to reduce the subjectivity of the cognitive model. The Kanva system is based on a mathematical apparatus of fuzzy logic. Fuzzy logic is a convenient tool that allows a user who is not an expert in mathematical modeling to establish logical connections between explanatory and dependent variables in financial and economic systems using natural language expressions, and to make mathematically valid analyzes and predictions of the development of these systems. The Kanva system has already been successfully applied in other scientific studies (Ismikhanov *et al.*, 2017).

Step 2: Parametrization of a cognitive map

To build a fuzzy cognitive map of resource management for the viability of the local community the system of input concepts for modeling in Table 1 were formed.

The cognitive map of resource management for the viability of a local community has the form of a parametric functional graph *Φ* using Eq. 1.

$$\hat{O} = G, X, F, \theta, \quad (1)$$

where $G = \langle V, W \rangle$ – is the sign oriented graph of resource management for the viability of a local community; $V = \{ v_1, v_2, ..., v_{15} \}$ – the set of the concepts of a model; W – is for binary relations on the set V, which specifies a set of relations between concepts; $w_{ij} = +1$, if growth (decrease) v_i causes

Table 1: System of input parameters of a fuzzy cognitive map of local community resources management

Input concepts (resources for the viability of a local community)	The name of the concept in the map	Measurement category	Measurement scale	Units of measurement
A group of local community resources				
The number of members	Membership	numeric	[0;100000]	persons
Complex quality indicator for management staff	Quality of managerial staff	linguistic	{"very low", "low", "average", "above average", "high", "very high"}	unit
Complex indicator of the telecommunication network state	Telecommunications	linguistic	{"very low", "low", "average", "above average", "high", "very high"}	unit
Complex indicator of infrastructure state	Infrastructure	linguistic	{"very low", "low", "average", "above average", "high", "very high"}	unit
Complex indicator of the suitability of chattels real estate	Real estate and equipment	linguistic	{"shortage", "delimitation", "sufficient", "more than enough"}	unit
Tourist attractiveness	Tourist attractiveness	linguistic	{"absent", "local significance", "regional significance", "state significance", "international significance"}	unit
A group of economic results of the activity of local community				
Tax revenues	Tax revenues	numeric	[0;100]	Million UAH
Own income per inhabitant	Own income per inhabitant	numeric	[0;50000]	UAH
Subsidy	Subsidy	numeric	[0;100]	Million UAH
Share of external financial resources	Liabilities	numeric	[0;100]	%
A group of additional parameters that ensure the viability of a local community				
The level of economic mobility	Mobility	linguistic	{"very low", "low", "average", "above average", "high", "very high"}	unit
Complex indicator of the state of the economic security system	Economic security	linguistic	{"absolutely dangerous","critical","dangerous","unsatisfactory","satisfactory","optimal"}	unit
Level of community members' participation in making decisions	Citizens' participation	linguistic	{"very low", "low", "average", "above average", "high", "very high"}	unit
Availability of an information management system	Information systems	linguistic	[0;1]	scale
Distance from the regional centers	Distance	linguistic	{"near the border of the regional center", "near", "not far", "far", "very far"}	unit

growth v_j; $w_{ij} = -1$, if growth (decrease) v_i causes decrease (growth) of v_j; $X = \{x_i\}$ – set of indicators of concepts estimation; $F = \{f_i\}$ – the concepts communications function; $f_i = \eta_{v_j}^{v_i} w_{ij}$; $\eta_{v_j}^{v_i}$ – weight of the interconnection from concept v_j to concept v_i; $i = \overline{1,n}$; $j = \overline{1,n}$ (n=15); $\theta = \{\theta_i\}$ – the range of values of estimation indicators of cognitive model concepts.

The cognitive map is determinate, since the value of the factor at the vertex is interpreted as its absolute value, expressed in the corresponding units of measure or linguistic estimates. In the Kanva system, for the elements of the linguistic values range of the concepts $L_i = \{l_{i1} ..., l_{im}\}$ not only the strict order of the values $l_{i1} < l_{i2} < ... < l_{im}$, but also the equality of the intervals between the linguistic values is defined. The equality of the intervals between the values of the concepts is established with the help of the Torgerson expert method of dividing the segment in half. The factor scale in the Kanva system is defined as the mapping of each linguistic value of the factor to the point of the number axis, $\varphi: L_i \to X_i$, $X_i = \{x_{i1} ..., x_{in}\}$, $x_{i1} ... x_{in} \in [0,1]$. The inverse reflection $\varphi^{-1}: x \to l_i, x \in [0,1]$ enables interpretation of any value of x into the linguistic value of the factor l_i, $l_i \in L_i$. Cause and effect relations between concepts of a cognitive map are described by the system of mapping equations type "If ...Then

...". In the matrix form, this system of equations is written as Eq. 2.

$$\mathbf{Z}(\mathbf{t}+1)=\mathbf{W}^{o}\mathbf{Z}(\mathbf{t}), \quad (2)$$

Where, $Z(t)=(z_i(t))$ – the initial vector of the values increments of local community management resources at time t; $Z(t+1)=(z_i(t+1))$ – vector of the values increment of the local community management resources at time $t+1$, $z_i(t)\in [-1;1]$; $W=|f_{ij}|$ – adjacency matrix; $f_{ij}\in [-1;1]$ characterizes the causal link force. The increment of the map concept (the resource for the viability of the local community) $z_i(t)\in Z(t), \forall t,$ is represented by a pair (Kulinich, 2014): $(z_i(t), c_i(t))$, $c_i(t)$ – consonance of the local community resource value, $0\leq c_i(t)\leq 1$, using Eq. 3.

$$c_i(t)=\frac{\left|z_i^{+}(t)+z_i^{-}(t)\right|}{\left|z_i^{+}(t)\right|+\left|z_i^{-}(t)\right|}. \quad (3)$$

Consonance characterizes the confidence of the subject in incrementing of the other concept value of $z_i(t)$. For $c_i(t)\approx 1$, i.e. $z_i^+(t)>>|z_i^-(t)|$ or $|z_i^-(t)|>>z_i^+(t)$ the confidence of the subject in the value of $z_i(t)$ is maximal, and for $c_i(t)\approx 0$, i.e. $z_i^+(t)\approx |z_i^-(t)|$, is minimum. Intervals of the consonance values in the Kanva system have a linguistic interpretation {"Impossible", "Weakly possible", "Almost possible", "Possible", "Very Possible", "Almost Reliable", "Trustworthy"}. In the subsequent study, we will consider the simulation results to be reliable (or reflecting the situation correctly) with the value of the concept consonance of $0{,}5\leq c_i(t)\leq 1$ 1 (from "Possible" to "Trustworthy"). Thus, the reliable forecast of the development of the situation by the time $t+1$ is defined by the pair, using Eq. 4.

$$Z(t+1), C(t+1), \quad (4)$$

Where, $Z(t+1)$ – is the vector of values increment of the concept at time $t+1$; $C(t+1)$ – is vector of consonance at the moment $t+1$; $c_i\in [0{,}5, 1]$.

The use of the fuzzy cognitive mapping is suggested for solving the following tasks:

- A formal description of the relation system between the concepts of a cognitive map necessary to understand and explain the mechanism of phenomena and processes in it;
- Study of the structural properties of the system, reflected in a cognitive map, analysis of the stability of its behavior to structural changes, various influences of the internal and external environment;
- Simulation of possible scenarios for system development and their further analysis using scenario analysis methods.

In order to justify the choice of managerial influences in developing scenarios, it is proposed to apply the pulse modeling method. External momentum at the moment t – a set of perturbations, $Q(t)=\{Q_v(t), v\in V\}$.

- The model of the impulse process is a tuple: $\hat{O}, Q, A$, where Φ – a vector functional graph; $Q=Q(t_n)$ – A sequence of disturbing actions; A – parameter change rule.

Generally, the impulse process may be influenced by the action of external impulses at any given time. In this case, we will assume that $q_j(t)$ represents an external shocks or a change in the vertex v_j, at the moment t ($q_j(t)$ added to the vertex value v_j). Thus, the complete formula for the pulse process will look this way using Eq. 5.

$$v_i(t+1)=v_j(t)+q_j(t+1)+\sum_{j=1}^{n} s(v_j, v_i)p_j(t), \quad i=1,2,\ldots,k. \quad (5)$$

Initial conditions were assigned by the value of $q_j(t)$ for all j. Consequently, the impulse process simulates the management system influence on certain resources of the local community and allows analyzing the dynamics of local community resources depending on managerial impulses.

The study of the dynamics of local community resources using a cognitive map requires the construction of a scenario for its behavior. The scenario $\Re$ of the behavior of the object from the standpoint of the decision maker is the sequence of pairs $(I(t_n), t_n)$, formed in accordance with the rule of choice A: $\Re=\Re\{(I(t_n), t_n)|t_n\in A\}$ where $n=0,1,\ldots,N; t_0=0$, and where N – the depth of the scenario; $T=t_N$ – the forecast horizon. The scenario analysis of local community resources management involves simulating the development of a situation with different management influences and a comparative analysis of the situation development forecasts, their quantitative and qualitative assessment with a view to choosing a better strategy for managing local community resources. The Kanva system allows us to assess the consistency and plausibility of composite scenarios and, if necessary, eliminate combinations of finals that are incredible or impossible, as well as evaluate the resulting scenarios in terms of achieving goals. Scenario study of various strategies for achieving the goal is carried out in the information Kanva system in the subsystem of comparing scenarios of the situation. This subsystem provides the opportunity to pair and compare two scenarios of the situation. Then, basing on the user's analysis, the most appropriate management scenarios are selected.

Step 3: Creating a list of management impacts on a local community

By solving the direct problem of cognitive mapping, the prognosis of trends in the change of local community managed resources is carried out and a list of managerial influences on them is formed.

Step 4: Developing a strategy for local community management

At the last stage of cognitive mapping, within the framework of solving the inverse problem, variants of resource management strategies for the local community viability are developed and recommendations for their implementation are provided.

RESULTS AND DISCUSSION

The result of the formalization of the causal relations between resources for the viability of a local community (concepts) was creating of a system of relations between concepts in the form of a causative network – a cognitive map of management of local community resources (Fig. 1). The red one represents a positive causal link, the blue one is used for negative. From the structural analysis of the cognitive model, the conclusion on the stability of the system to single local influence was drawn: the system is inertial, since the change of any concept does not make significant changes in other concepts, in addition, changes in the system as a whole lead to a weakening of the original value change of the concept. In order to achieve the desired effect, multiple impulses need to be introduced into the guided concepts, and, consequently, resource management for the viability of a local community should be a continuous process. During simulation experiments with a cognitive map, impulse input to some concepts was found to have led to a reliable result (Table 2), and, therefore, these impulses are managed resources for the viability of a local community.

The presence of reliable results in introducing the impulse and other concepts gave us the grounds for allocating indirectly managed resources for the viability of a local community (Table 2). The

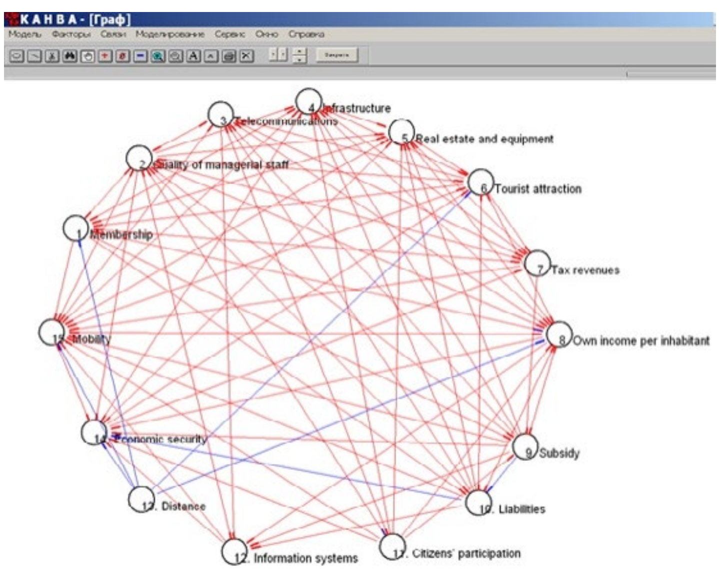

Fig. 1: A graph of fuzzy cognitive mapping of the local community resources

Table 2: Grouping of resources for the viability of a local community according to its manageability

The name of the concept on the map	c_i
Managed resources for the viability of a local community	
Quality of managerial staff	0,51
Tourist attraction	0,58
Tax revenues	0,74
Mobility	0,62
Economic security	0,62
Indirectly managed resources for the viability of a local community	
Membership	0,51 – 0,63
Telecommunications	0,50 – 0,63
Infrastructure	0,51 – 0,63
Real estate and equipment	0,51 – 0,64
Own income per inhabitant	0,50 – 0,72
Subsidy	0,55 – 0,63
Liabilities	0,51 – 0,59
Citizens' participation	0,57 – 0,87
Information systems	0,58 – 0,84
Unmanaged resources for the viability of a local community	
Distance	0,0

Table 3: Strategies for the growth of the '*own income per inhabitant figure*'

The name of the strategy	Managing concept	The change in managing concept	Consonance for the concept of the 'own income per inhabitant'
Increase in quality of managerial staff	*Quality of managerial staff*	from "low" to "average"	0,63
Increase in tourist attraction	*Tourist attraction*	from "local significance" to "regional significance"	0,72
Increase in tax revenues	*Tax revenues*	increased by 165%	0,72
Increase in economic mobility	*Mobility*	from "very low" to "low"	0,68
Improvement of economic security	*Economic security*	from "critical" to "satisfactory"	0,68

remoteness of the local community from the regional centers affects other concepts, but is an unmanaged resource. In the simulation study, in order to construct scenarios of resource management for sustainability of a local community, 'own income per inhabitant' as an indicator of self-selection area potential of a local community has been chosen as the target concept. In the process of dialogue with the Kanva system there were strategies designed to achieve the target value of the 'own income per inhabitant' concept at a level 30% higher than the original. As a result of modeling, strategies for the growth of 'own income per inhabitant' have been proposed (Table 3). The consonance values for the target concept obtained indicate the probability of each strategy being implemented.

Thus, state of the 'own income per inhabitant' figure in the future can be improved if five guided concepts can increase significantly. For the further development of resource management scenarios for the sustainability of local community's, it is necessary to take into account the current state of the concepts of certain local community's, the values of unmanaged and partially managed concepts and the available resource constraints. Consideration of resource constraints for the local community's of the individual regions in Ukraine provided grounds for concluding that it was not possible to implement the proposed strategies only by using the management concept (Table 3) and that there is the need for a combined resource management for the sustainability of a local community. The most possible growth of the 'own income per inhabitant' concept was achieved with the simultaneous influence on the management concepts and the concepts of real estate and equipment, citizens' participation, information systems. The additional effects of implementing such scenarios were the growth of the concepts of Liabilities, Subsidy and Tax revenues.

CONCLUSION

In the course of the research, the applied task to make a list of significant resources that can be effectively controlled in the management of the viability of a local community was solved using the methods of economics and mathematical modeling. Fuzzy cognitive mapping was used as the basic methodology. To get solutions, a system of resources for a viable local community – concepts for a model (Table 1) has been identified. In the Kanva system, a fuzzy cognitive map of local community resources management was built (Fig. 1). During simulation experiments with a fuzzy cognitive map of local community resources management, three groups of resources have been identified by impulse modeling as to the possibility of influencing them by local community managers to ensure the durability and sustainability of functioning: managed, indirectly managed and unmanaged (Table 2). The scenario analysis of resource management for a viable local community resulted in defining the target concept of the 'own income per inhabitant' as an indicator of an independent choice potential for the development of local communities, the change of which has defined several strategies. They are described in Table 3. The proposed model will allow the local community managers with no special engineering training in the future to determine their own management strategies to ensure the viability of a local community and its further progressive development.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

ABBREVIATIONS

Eq.	Equation
Fig.	Figure
IGLA	Intellektual'nyy generator luchshikh al'ternativ (Intelligent generator best alternatives)
MATLAB	Matrix Laboratory
UAH	Ukrainian hryvnia

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