Proceedings of the 2020 International Scientific Conference 'Economic Sciences for Agribusiness and Rural Economy'
No 4, Warsaw, 21–22 September 2020, pp. 55–60

ISBN 978-83-8237-063-8
ISSN 2658-1930
eISSN 2658-1965
DOI: 10.22630/ESARE.2020.4.7

# COGNITIVE MODELLING OF AN EFFECTIVE SYSTEM OF INFORMATION SUPPORT OF AGRICULTURAL ENTERPRISES

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## ABSTRACT

This article encompasses the methodology of cognitive modelling of complex poorly structured systems. Based on the expert method and with the help of this modelling methodology, the main factors that influence the effectiveness of information support of agricultural entrepreneurship were identified and the direction of their action was determined. There has been developed a cognitive map that reflects the cumulative impact of various factors on each other, as well as on the effectiveness of the information system for agricultural entrepreneurship. Hidden patterns between factors influencing the effectiveness of information support of agricultural entrepreneurship are revealed based on the cognitive map. The scenario approach is simulated based on different trends that reflect the current situation. This model allows us to further evaluate the performance of the system of information support of agricultural entrepreneurship under the influence of the environment, to predict its development, as well as to develop optimal strategic decisions that are aimed at ensuring sustainable development.

**Key words:** information support, cognitive approach, modelling, forecasting, poorly structured system; cognitive modelling of efficiency of functioning of the information system of agricultural entrepreneurship
**JEL codes:** C30, D80, Q13

## INTRODUCTION

One of the main elements of the whole management system of various forms of agricultural entrepreneurship is information support. It includes a set of communication processes, information resources, methods of their organization to perform effective management and analytical processes that will contribute to ensuring sustainable production and economic business activity.

It should be noted that cognitive modelling is one of the effective scientific methods that increase the level of management efficiency in complex economic systems. This method is based on modelling

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processes, which aim to establish different patterns of behaviour for a particular object, followed by the scientifically grounded decisions of its management.

The purpose of the article is to identify the main internal and external factors that affect the effectiveness of the information support system of agricultural entrepreneurship and forecasting based on a cognitive model of possible trends in the development of the system elements.

## THEORETICAL BACKGROUND

Various issues of the effective development of agricultural enterprises have been explored in the works of well-known economists, namely A. Malak-Rawlikowska, O. Yermakov (Yermakov and Kharchenko, 2014), T. Kalna-Dubinyuk (Kalna-Dubinyuk, Kharchenko and Kharchenko, 2016), S. Lupenko, S. Milovanović (Milovanović, 2014), and others. Scientific research of the cognitive method has been actively developing since the beginning of the 21st century. Axelrod is the founder of this approach (Axelrod, 1976). A significant contribution to the study of the problem of informatization and agricultural enterprises' economic activity has made such scientists as Z. Avdeeva, S. Kovryha and D. Makarenko (Avdeeva, Kovryha, Makarenko, 2007), J. Kania and J. Żmija (Kania and Żmija, 2016), B. Szafranska (Szafranska et al., 2020), D. Ross (Ross, 2005). However, the effectiveness of the agricultural information support system remains poorly researched and needs further study.

## MATERIALS AND METHODS

Cognitive modelling is one of the methods of effective management decision support. In general terms, the model is a simplified view of reality, which is used to explore its main properties. The 'cognitive' category comes from (latin *cognitio* – knowledge, cognition) and involves the mental perception and processing of external information. A cognitive approach is used to solve various process management tasks. This type of modelling combines structural system and simulation modelling that adequately reflect the object under study. This simulation method is relatively open to experts in various fields and allows them to develop mathematical models, the results of which are easily interpretable. The actual methodology of cognitive modelling is used to analyse and make decisions in poorly structured systems. Especially this approach allows modelling a set of information support processes for agricultural enterprises.

The purpose of cognitive modelling of poorly structured systems is to find out the mechanism of functioning of the system, to predict the development of the system, to control it, to determine the possibilities of its adaptation to the external environment. Cognitive modelling in terms of analysis and management of poorly structured systems is a study of the functioning and development of poorly structured systems and situations by building a model of a poorly structured system based on a cognitive map. In this model, the cognitive map reflects the idea of the problem under study, the situation associated with the functioning and development of a poorly structured system. The basic elements of the cognitive map are the underlying factors and the causal relationships between them.

It should be noted that cognitive analysis is a preliminary stage of cognitive modelling based on graph language, which is a convenient tool for describing various physical, technical, economic, and other systems.

So, the task of analysing situations based on cognitive maps is divided into static and dynamic. Static or impact analysis is the analysis of the system under study by examining the structure of the interconnections of the cognitive map, which allows us to identify the structure of the system, find the most important component elements, evaluate their mutual influence. The study of the interaction of component elements makes it possible to estimate the spread of influence on the cognitive map, which changes their state. Dynamic analysis is the basis for the generation of possible scenarios for the development of the situation over time (impulse modelling).

At the first stage of the cognitive analysis application and modelling of complex systems, there is performed the cognitive model development by constructing a cognitive map, or as a parametric vector functional graph of the following form (Horelova, Zakharova and Hynys, 2005):

$$\Phi_n = \langle G, X, F, \theta \rangle, \quad (1)$$

where:

$G$ – oriented graph (cognitive map), $G = \langle V, E \rangle$;

$V$ – set of vertices, $V = \{v_i \mid v_j \in V, i = 1, 2, ..., k\}$ and their elements $v_{ij} \in V, ij = 1, 2, ..., k$;

$E$ – set of arcs $E = \{e_i \mid e_j \in E, i = 1, 2, ..., k\}$ and arcs $e_{ij} \in E, ij = 1, 2, ..., k$ that reproduce the relationship between the vertices $V_i$ and $V_j$;

$F = f\{v_i, v_j, e_{ij}\}$ – function that reflects the relationship between vertices $V_i$ and $V_j$;

$X$ – set of vertex parameters, where $X = \{X^{(v_i)} \mid X^{(v_i)} \in X, i = 1, 2, ..., k\}$, $X^{(v_i)} = \{x^{(i)}{}_g\}, g = 1, 2, ..., l, x^{(i)}{}_g$;

$g$ – vertex parameters $V_i$, if $g = 1$, then $x^{(i)}{}_g = x_i$;

$\theta$ – space of parameters of vertices, each vertex corresponds to a vector of independent variables.

Also, the cognitive map can be reproduced not only graphically but also by the matrix of relations $A_G$. Given a square matrix, in which rows and columns are denoted by vertices of the graph, as well as at the intersection of the *i*-th row of the *j*-th column, there are (or not) 1 or 0, if there is (or not) a relation between the elements $V_i$ and $V_j$ in the following form:

$$A_G = [a_{ij}]_{k \cdot k}, \quad (2)$$

where $a_{ij} = 1$ if $V_i$ is related to $V_j$; provided that $V_i$ is not related to $V_j$ then $a_{ij} = 0$.

Generally, cognitive modelling is performed step by step or impulse. In impulse modelling, some impulse (change) of an indicator occurs on any one or more vertices of a graph. These actions disrupt the entire metric system and transit the system from one state to another.

If there are several vertices $V_j$ correspondingly adjacent to $V_i$ then the process of perturbations spreading on the graph in the presence of internal pulses $P_j$ and the absence of external perturbations is calculated by Equation (3) (Walliser, 2008):

$$X_i\,(n + 1) = X_i\,(n) + \sum f(X_i, X_j, e_{ij}) P_j\,(n), \quad (3)$$

*f* the initial values of $X(n = 0)$ are known in all vertices and the initial perturbation vector $P$ (0). In the case where there are external perturbations $Q_i$, the impulse process is determined by Equation (4):

$$X_i\,(n + 1) = X_i\,(n) + \sum f(X_i, X_j, e_{ij}) P_j(n) + Q_i\,(\mathrm{n} + 1). \quad (4)$$

The model of impulse processes can also be presented in a matrix form, which is convenient when modelling on sign graphs. Suppose that the vector of vertex parameters at a certain time *t* is given by Equation (4). Then the change in the parameters of the vertices in the general case will be given by this equation:

$$X_i\,(n + 1) = X_i\,(n) + AP(n) + Q_i\,(n + 1), \quad (5)$$

where $A$ is the matrix of relations $G$ of the cognitive map. We obtain from Equation (5) concerning Equation (4) for $P(n)$.

$$P(n) = A^{n-1}\,Q_0 + A^{n-2}\,Q_1 + \cdots + AQ_{n-2} + \mathrm{I}Q_{n-1}, \quad (6)$$

where I is a unit matrix.

So, to develop a cognitive model and use it as a predictive one, the following steps must be completed: (1) Build a cognitive model according to the available quantitative and qualitative information. (2) Perform scenario modelling (using impulse modelling) based on a cognitive model that reflects the possible development of situations in the system under study – the prediction of situations development. (3) Compare simulation results with observational data.

## RESEARCH RESULTS AND DISCUSSION

The effectiveness of the formation and use of information systems for agricultural entrepreneurship is affected by various organizational, economic, social, and other factors. Actually, the information system for agricultural entrepreneurship is poorly structured because it has complex interconnections between different elements (Kharchenko, Kharchenko and Malak-Rawlikowska, 2018).

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Therefore, to ensure the conditions for the effective functioning and development of the information system for agricultural entrepreneurship, it is necessary to study the influence of the main internal and external factors on this system, as well as to identify the interaction of these factors with each other. With the help of experts, the most important factors were selected under the influence of which the formation of the level of functioning efficiency of the information support system of agricultural entrepreneurship is formed:

1. The effectiveness of the information support system.
2. Information transmission hardware.
3. Client and server software for data transmission and processing.
4. Developed IT infrastructure and Internet.
5. Increasing the level of IT awareness among staff.
6. Legal regulation of information support processes.
7. The level of innovation processes.
8. Access to analytical information sources when making management decisions.
9. Organization of information security.
10. The level of investment and investment in the implementation of information support.
11. Functioning efficiency of information-consulting centres.
12. The price level for hardware and software.

These variables are vertices of the graph. Note that these factors affect each other. Yes, if one factor increases or decreases, leading to another factor increasing or decreasing, the impact will be considered positive. If an increase in the level of a certain factor causes a decrease in the level of another factor, then this influence is negative.

It should be noted that it is the cognitive map and further analysis of the level of information system efficiency of agricultural entrepreneurship that will identify the factors that need operational development and need to be improved. On this basis, a cognitive model was constructed, based on external and internal environmental factors, and the direction of their action was determined (Fig. 1).

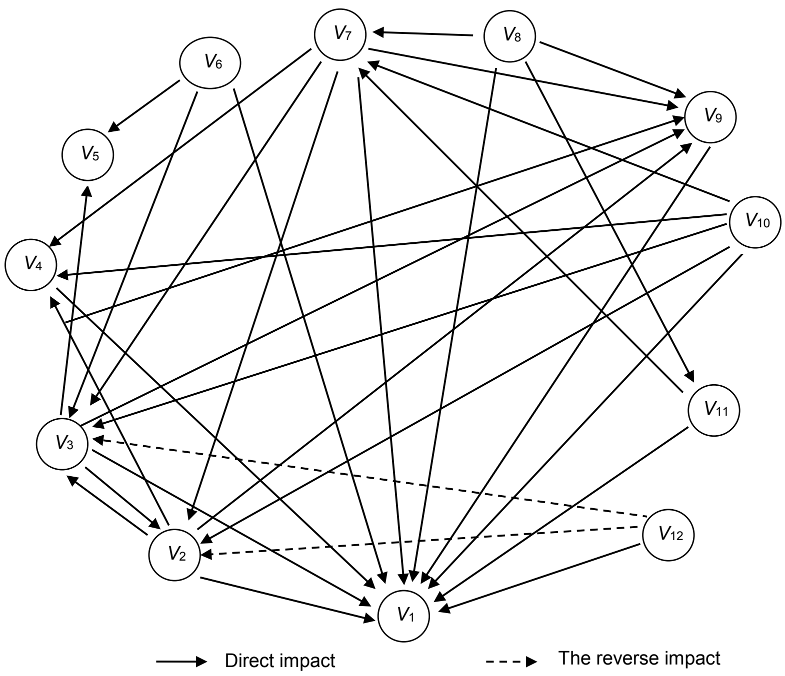


**Figure 1.** The cognitive model of internal and external factors influences the effectiveness of the information support system of agricultural entrepreneurship

Source: developed by the authors.

Considering that in a linear dynamic model, which is based on a cognitive map, the studied factor is defined as a variable that takes values from some numerical scale. The set of interrelations of different factors of the model is given in the matrix of adjacencies of vertices of the oriented graph (Table 1).

In this case, the vector functional graph of the system functioning of information support efficiency of agricultural entrepreneurship is given by the corresponding matrix. In the matrix, the number +1 means that if $V_i$ increases, there will be an increase in $V_j$, a negative number –1 indicates that if $V_i$ increases, there will be a decrease in the factor $V_j$, the number 0 indicates a weak connection or none at all. A cognitive map that has been developed reflects the cumulative impact of various factors on each other, as well as on the effectiveness of the information system for agricultural entrepreneurship. The scenario approach was then modelled based on different trends that reflect the current situation.

In impulse modelling, +1 changes were made alternately to each of the vertices of $V_n$, which makes it possible to trace and determine the influence of a single n factor on the effectiveness of the information system of agricultural entrepreneurship. Table 1 shows the modelling results when you make $a + 1$ change to the vertex 'capital investment and investment', with six modelling cycles.

In Figure 2, the abscissa axis shows six modelling cycles ($n = 1, 2, 3, 4, 5, 6$), and the ordinate axis shows changes in the indicator values in relative units.

**Table 1.** The results of the impulse process modelling, when you make $a + 1$ change to the vertex $V_{10}$

| Variable | $V_1$ | $V_2$ | $V_3$ | $V_4$ | $V_5$ | $V_6$ | $V_7$ | $V_8$ | $V_9$ | $V_{10}$ | $V_{11}$ | $V_{12}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $X_0$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $X_1$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| $X_2$ | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| $X_3$ | 5 | 3 | 3 | 3 | 1 | 0 | 1 | 0 | 4 | 1 | 0 | 0 |
| $X_4$ | 15 | 5 | 5 | 5 | 3 | 0 | 1 | 0 | 11 | 1 | 0 | 0 |
| $X_5$ | 28 | 7 | 7 | 7 | 5 | 0 | 1 | 0 | 19 | 1 | 0 | 0 |
| $X_6$ | 42 | 9 | 9 | 9 | 7 | 0 | 1 | 0 | 27 | 1 | 0 | 0 |

Source: the authors' calculations.

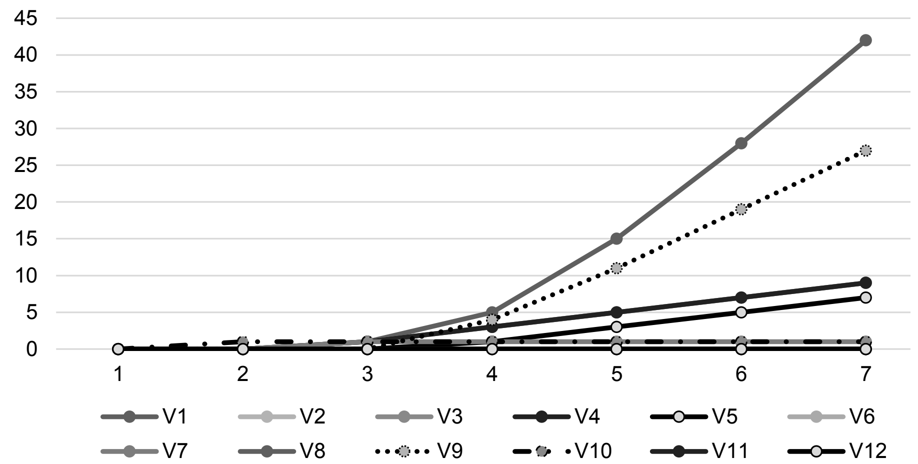


**Figure 2.** Graphic representation of the impulse change in vertices $V_1$–$V_{12}$, when the +1 is changed in vertex $V_{10}$

Source: the authors' calculations.

The results of the scenario modelling make it possible to conclude that with the increase of investments there is an increase in the level of efficiency of the information support system of agricultural entrepreneurship.

It should be noted that the peculiarity of the forecast obtained using the cognitive model reflects the directions of the processes developed in the system under study. It reproduces alternative ways of developing the system, providing the changes in the various elements that will affect it in the future. Therefore, the use of cognitive modelling based on the object observation allows obtaining the prediction results using the impulse modelling method on cognitive maps.

## CONCLUSIONS

A built-up, vague cognitive map is an objective approximate way to build an adequate model of the information system efficiency of agricultural entrepreneurship. With the help of the developed model, it is possible to identify factors that positively and negatively affect the functioning and development of the system, identify hidden patterns between factors, carry out cognitive modelling, which in the complex will allow to evaluate the performance of the information system of agricultural entrepreneurship under the influence of the environment and to predict its development. The cognitive model explains which component element or interrelationship of elements must be influenced, with what force and in which direction, to achieve the goal with minimal costs. A properly constructed cognitive model allows the expert to develop the correct solution to problem situations in complex, poorly structured systems.

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