CHAPTER 15

Intellectual Evaluation of the Economic Systems' Performance in Post-Industrial Society

Antonina Kazelskaya and Igor Stepnov

Introduction

The fatality of errors in the forecasts of economic systems remains a pressing issue. When analysing the complex processes of their functioning, decision-makers face various types of stochastic uncertainties, amongst others. The lack of a universal risk management methodology for different types of economic systems can be explained by the specificity of each organization's business processes. Most approaches do not address the issues of quantifying the damage caused by external and internal impacts on economic systems. There is no analysis of the sensitivity of damage

A. Kazelskaya
Audit of Your Business LLC, Ryazan, Russia

I. Stepnov (✉)
Moscow State Institute of International Relations (MGIMO University), Moscow, Russia

Financial University under the Government of the Russian Federation, Moscow, Russia

J. Kovalchuk (ed.), *Post-Industrial Society*,
https://doi.org/10.1007/978-3-030-59739-9_15

estimates to major disturbances or vulnerabilities. The choice of effective countermeasures to reduce risks is not always justified.

Thus, the intended effectiveness of economic systems' management tools on data analysis is far from actually being implemented (Glushenko 2017). There are virtually no methods to improve the management of those economic systems that support the correlation of data from external sources, risk management, and cognitive modelling, let alone that can assess their functioning. This research aims to increase the efficiency of economic systems' management.

We used the mathematical algorithms based on neuro-fuzzy networks and cognitive modelling; doing so, we were able to identify the threats of external influences and to determine the current state of the economic system.

Methodology

Cognitive concepts are based on the uncertainty of the economic systems' development (Papageorgiou and Poczęta 2017). This uncertainty is expressed through the diverse possibilities for the world may transform, within the existence of a set (usually an infinite number) of system states, in which the object (economic system) is considered in the dynamics. The concept of uncertainty concerning these economic systems characterizes a situation in which reliable information about the possible conditions of the internal and the external environment is completely or partially lacking. "Uncertainty" is considered to be an incomplete or inaccurate representation of various parameters in the future, caused by various reasons but, above all, caused by the incompleteness or inaccuracy of the information available about the terms of decision implementation, including costs and results.

This is why it is no accident that study into the problems of uncertainty, the searching and processing of information, and the management of expectations—which are of primary importance when there is only incomplete information—has become the main foundation for the development of economic theory. Nowadays, the definition of the modern stage of economic development as a transition to the "knowledge economy" is generally accepted.

Results

For managing the economic system despite the conditions of uncertainty, it is necessary to simulate the dynamic situation, in which an expert (a person who creates a subjective model of reality based on their observations, knowledge and experience) measures its parameters. When creating a subjective model, the expert identifies the most significant part of the situation from their point of view, then makes a qualitative description of their knowledge and its interrelation.

It makes sense to use fuzzy cognitive maps to influence a variety of destabilizing interrelated events (Averkin and Yarushev 2017). This is a kind of mathematical model that allows the description of a complex object, problem, or the system's functioning to be formalized, and also helps to identify the structures of cause-effect relationships between elements of the system and elements of the problem, and assesses the impact after influencing these elements or changing the nature of their linkages.

Cognitive graphs differ in clarity due to the transition from verbal information (or other symbolic paths) to a visual image (Carvalho and Tome 1999). Cognitive maps can be used to describe various situations, depending upon the analysis needed to identify the possible ways to develop the system (Olier et al. 2018). Their main advantages lie in the ability to visualize the factors of organizational development, and to interpret their mutual influence naturally.

Thus, a fuzzy cognitive map can be represented as an oriented, weighted graph; its vertices represent concepts, entities, factors, goals, and events, and its arcs represent cause-and-effect relationships and their impact. The influence is characterized by a certain threshold function based on expert evaluation, which is initially set in out through language.

Furthermore, the target factors include achieving the optimal order portfolio (matching production capacity to the order portfolio) and optimal capacity utilization; matching financial resources to the order portfolio; matching labour and material resources to the order portfolio; and matching actual indicators to the planned ones.

Formation is based on the following main factors: information obtained as a result of experts analysis of product availability; labour, financial and material resources; and the compliance of the order portfolio.

The basic factors are: the order portfolio, production capacity, the availability of financial and labour resources, and availability of material resources.

At the second stage of situational modelling, we will form a set of problem situations that arise while developing a production programme and which require certain management decisions to be made. One of the most rational approaches may be to form subsets of problem management situations by objects, that is, to determine deviations in a system from the target factors.

In this context, deviation from the target factor will be the expected as the non-fulfilment of output, due to the influence problem factors have upon the basic factors.

The list of problems includes the following:

- a lack of orders;
- insufficient production capacity; full load, resulting in wear and tear, and frequent failure or incomplete production capacity;
- production potential being mismatched to the order portfolio;
- a lack of financial resources;
- a lack of qualified personnel;
- a lack of material resources;
- failure to comply with the production plan;
- failure to implement the plan.

The next step is to identify the factors that negatively impact the problem factors (the negative impact is that its change leads to an undesirable change in at least one problem factor). To do this, symptoms were identified and noted for each of the identified problem factors. Based on observations and on in-depth interviews with experts, each management decision determines its symptoms and identifies its relevant problem factors.

Causes for this include:

- low demand; employing the wrong marketing policy;
- a lack of the equipment necessary for the market; "bottlenecks"; a lack of financial resources to re-equip the fixed assets; the need to modernize equipment; an insufficient portfolio of orders, or insufficient production capacity;
- high demand; insufficient production capacity, or an insufficient portfolio of orders, or insufficient resources of the enterprise;
- high interest rates; the growth or decline of the exchange rate; the absence of external investors; inflation or increased costs of the

enterprise; lack of management accounting; decrease in sales volumes; misuse of funds;
- a lack of university graduates; lack of targeted training programmes; ineffective retraining of personnel; insufficient personnel capable of working on new equipment; insufficient incentive system;
- the supplier left the market; a lack of financial resources; over-planned waste of raw materials; errors in the planning of delivery and storage; incorrect resource distribution;
- violation of plans for the supply of material resources; violation of financing plans by buyers or creditors; inefficient use of material and labour resources; disruption of the production process;
- insolvency of demand, or failure to comply with the production plan; failures in transport support.

The third stage includes: defining the structure of the problem, and systematizing the factors that contribute to the problem. This stage is where the strategy is determined.

This is followed by defining a control action that can change the situation. The system development model is analysed. A controlling influence is formed that improves the situation. It is necessary to consider the mechanism capable of reacting to the reasons analysed—this can be elimination or compensation. Elimination partially impacts the target factors by removing or weakening the factors causing them. Compensation involves identifying the control factors that positively impact targets despite persistent problems. The control effect is formed under either active or passive control.

Thus, the vector of control influence is formed by changing the conditions under which management decisions are made.

Established control effects include:

- those for a problem when creating an insufficient order portfolio or a full load portfolio: diversification of production; the search for new customers; improvements of marketing policy.
- those for solving the problem by creating insufficient production capacity: identifying and eliminating bottlenecks in production; re-equipping fixed assets; eliminating the shortage of financial resources;
- those for solving the problem of insufficient production capacity: solving the problem of an insufficient order portfolio;

- those for solving the problem of non-compliance with the order portfolio: solving the problem of insufficient production capacity or an insufficient order portfolio;
- those for the problem of a shortage of financial resources: lending; sale or lease of unused equipment and premises; the search for new investors; improvement of cash flow control; organization of management accounting;
- those for the problem of a shortage of financial resources: revising retraining policy; revising personnel policy; target direction; solving the problem of the shortage of financial resources;
- those for the problem of a shortage of material resources: searching for new suppliers; solving the problem of the shortage in financial resources;
- those for the problem of non-compliance with the production plan: retrofitting fixed assets; training employees; applying new technologies in production;
- those for the problem of non-compliance with the production plan: reviewing the marketing opportunities.

All authors who deal with the cognitive approach use cognitive maps—in the form of a sign or weighted graph over a set of factors—in which the vertices are the aforementioned factors, and the edges are the weight of one scale or another.

Different interpretations of vertices, edges, and weights, as well as different functions that determine the influence of connections on factors, lead to the creation of different modifications for cognitive maps, as well as the means to study them. At the same time, interpretations can differ both in terms of substance and in mathematical terms. Due to many modifications of cognitive maps, it is possible to see different types of models based on these maps.

Verification (establishing the truth of a cognitive map) is performed in various ways, including:

1. the method of alternatives: based on checking the obtained values in vertices or the model as a whole, using alternative approaches and mathematical or statistical methods such as the Monte Carlo method or simulation techniques;
2. the historical method: compare the output of each arc with real data from previous periods.

To check if the cognitive map is suitable for creating the production programme, the author has selected a method for analysing hierarchies, with which it is possible to

- provide a hierarchical representation describing the impact of changing priorities at the highest levels on the priorities of lower-level elements. Thus, a static analysis of influence is implemented; that is, the situation can be analysed by studying the structure of mutual influences using the cognitive map, highlighting the key factors that influence the target factors;
- enable direct and reverse hierarchical planning, and implement dynamic analysis (generating possible scenarios for the situation over time).

Each scenario describes the state of the system. Many state variables are used to understand and characterize them. These define the structure and threads of the system in this state. We have defined many state variables and used them to describe the result of our planning. These variables have been classified via different outcome aspects, such as: labour, production, material, financial resources, and portfolio security.

Each of the main scenarios is described using the language of change, showing how each of these variables differs from the status quo. The intensity of each of these variables is measured using a scale of differences, in the range -5 to +5.

A simple scale from 1 to 5 is an overestimation of the indicators for state variables, due to the influence control actions (as formed under the conditions defined by the scenario) have on the situation. Similarly, -5 to -1 as a scale understates indicators; 0 is a value indicator under the given scenario, whereby conditions does not change.

The following parameters of a direct process were defined:

I. Focus formation of the production programme.
II. The forces that influence the outcome. The main factors in the formation of the production programme include: labour, production, material, and financial resource security; the portfolio of orders.
III. Actors include: production capacity, portfolio of orders, material resources, human resources.

IV. Conditions for creating influences include: low demand, inflation, high interest rates, and so on.
V. Primary factors: re-equipment of fixed assets; lending, and so on.
VI. Three actions: overestimating indicators under the influence of wagering; underestimating indicators under influence; the real reflection of indicators.
VII. Scenarios:
- An increase in production programme indicators.
- A sequential increase in the security of labour and production resources, and so on.
- A simultaneous increase in the estimates of labour and production resources, and so on.
- Alternatively:
- Lower output from the production programme:
- The successive lowering of the labour resource security, production, and so on;
- A simultaneous decrease in available labour and production resources, and so on.

VIII. State variables:
- Endowment of labour resources
- Endowment of production resources
- Endowment of material resources
- Endowment of financial resources
- Portfolio security

To repeat, 1–5 is an overestimation of indicators of state variables due to influence; -1 to -5 is an underestimation; 0 means that indicators do not change.

The subject of the study is the values of the “Weights of Scenarios” and “Generalized Weights” patterns.

The study found answers to the following questions:

1. What management decision has the greatest impact on the formation of the production programme?

Currently, each pair of characteristics is compared in terms of their impact on the factors.

2.1 Which actor has the greatest impact on labour resources?

2.2 Which actor has the greatest impact on production resources?
2.3 Which actor has the greatest impact on material resources?
2.4 Which actor has the greatest impact on financial resources?
2.5 Which actor has the greatest impact on the security of the orders' portfolio?

The next step is to identify the conditions in which the actors operate and to identify the most characteristic conditions. The result is a custom vector that reflects the order and weight of the conditions.

3.1 What are the working conditions for credit institutions?
3.2 What are the operating conditions specific to the production capacity?
3.3 What working conditions are typical for customers?
3.4 What working conditions are typical for suppliers?
3.5 What working conditions are typical for investors?
3.6 What working conditions are typical of transport companies?

And so on.

We will determine what factors affect the actors based on the conditions in which they operate.

4.1 What factors affect production capacity when it is fully loaded?

And so on.

4.2 What is necessary to affect the customers in low demand?

And so on.

4.3 What effects on suppliers are necessary when the main supplier leaves the market?

And so on.

4.4 Each influence makes the actor perform actions that change the performance of the production programme. Therefore, for each influence, we define the actions of the actors to which they lead.

5.1 What "actions" of production capacity are likely to result in fixed assets being re-equipped when they are insufficient?
And so on.
5.2 What actions are likely to result in a change in marketing policy when demand is low?
And so on.
5.3 What actions by suppliers will likely result in the search for new suppliers when the main supplier is unavailable?

And so on. The last step necessary for obtaining scenario weights is to develop dominance matrices with respect to each action for the scenarios.

6.1 Which scenario is most defined by an increase in production capacity?
6.2 Which scenario is most defined by an increase in financial resource availability?

And so on. All in all, it is necessary to create a generalized scenario, which can be realized after the values of each characteristic have been determined using the generalized measurement scale.

The generalized scenario is interpreted as follows:

If the production programme is created, and certain actions that form certain goals for different actors are necessary, it is possible to change the indicators of the production programme. In particular, indicators of production and labour resources, as well as those of the order portfolio security, will be increased. Therefore, the results of evaluating financial resources have been significantly reduced. As for material resources, they will be virtually unaffected by the existing impacts.

A qualitative analysis of the cognitive model includes defining the routes, paths, and cycles needed to study the various cause-and-effect relationships in the system under study, as are displayed by the cognitive model. When managing socio-economic systems, it is necessary to know the forward and feedback cycles necessary for judging the system stability/instability.

Using a cognitive map to create the production programme, the influence of situation factors was found, evaluated, and obtained, based on the calculated influence of the forecasts.

Cognitive maps have a significant drawback—the need for painstaking expert work to identify cause-and-effect relationships between concepts in the system, as well as to adjust the weights of these relationships.

However, using a cognitive map makes it possible to make a qualitative forecast of the production programme, and to identify the most influential factors that can be used as inputs in the neural network. They include: crediting, re-equipment of fixed assets, changing the marketing policy.

Neural networks can allow the teaching of fuzzy cognitive maps. The training task is formulated to minimize errors in the prediction results of a fuzzy cognitive map.

Cognitive maps will be taught to represent their factors (concepts) as neurons, and contour parameters (synapses) as weights of the cognitive map's connections, which change so that they match the data as much as possible.

However, using a cognitive map means making a qualitative forecast of the production programme is possible, so the most influential factors that will be used as inputs in the neural network can be identified. These include: crediting, re-equipment of fixed assets, changing the marketing policy.

When choosing a network architecture, it is necessary to follow the requirements of the network operation accuracy, as well as the complexity and time of its training. As for forming a production programme, it is impossible to model neural networks with linear functions of neuron activation, since not all parameters are cumulative. This means that the characteristics of the production programme cannot change linearly when the input parameter vector is changed accordingly.

The next stage includes training the neural network, that is, determining the values of weight coefficients that provide a unique conversion of input signals to output.

By analysing the available input and output data, the network weights are automatically built to minimize the difference between the desired signal and the one obtained at the output after the simulation. This difference is called a learning error.

The error of a particular neural network configuration can be determined by analysing all available observations using the network, and comparing its output values with the desired target values. These differences make it possible to form a so-called error function (a criterion for learning quality).

It should be noted that, in general, it is impossible to guarantee that the global minimum of the error function can be reached for neural networks with non-linear activation functions.

In the case of a non-linear activation function for training neural networks, we propose applying the method of reverse propagation of the error.

Conclusions

Using a cognitive map for creating a production programme, the influence of situation factors was found, evaluated, and obtained, based on the influence of the forecasts calculated.

The neuro-fuzzy network allowed us to determine the quantitative characteristics of risk, such as the probability of implementing those factors identified in the cognitive map.

Therefore, following the dynamics of internal and external influences, changes in risks in the economic system were forecast. Using previously collected data allowed us to increase the accuracy of forecasts and risk treatment methods.

References

Averkin, A. N., & Yarushev, S. (2017). Hybrid Approach for Time Series Forecasting Based on ANFIS and Fuzzy Cognitive Maps. In *Proceedings of 2017 XX IEEE International Conference on Soft Computing and Measurements (SCM)* (pp. 379–381).

Carvalho, J. P., & Tome, J. A. B. (1999). Rule-Based Fuzzy Cognitive Maps and Fuzzy Cognitive Maps – A Comparative Study. In *Proceedings of the 18th International Conference of the North American Fuzzy Information Processing Society (NAFIPS99)* (pp. 115–119). https://doi.org/10.1109/NAFIPS.1999.781665.x.

Glushenko, S. A. (2017). An Adaptive Neuro-Fuzzy Inference System for Assessment of Risks to an Organization's Information Security. *Business Informatics, 39*(1), 68–77. https://doi.org/10.17323/1998-0663.2017.1.68.77.

Olier, A. J., Gómez, A., & Caro, M. F. (2018). Cognitive Modeling Process in Metacognitive Architecture. In *CARINA-2018 IEEE 17th International Conference on Cognitive Informatics & Cognitive Computing (ICCI*CC)*.

Papageorgiou, E. I., & Poczęta, K. (2017). A Two-Stage Model for Time Series Prediction Based on Fuzzy Cognitive Maps and Neural Networks. *Neurocomputing, 232*, 113–121.