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Intellectualization of economic and mathematical tools to support decision - making in the management of public finances in the context of digitalization

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***Abstract* — The purpose of this article is to develop economic and mathematical tools to support decision-making in the management of public Finance as a key area of digital development. Research meets modern trends of innovative development of the economy. The research of scientists in the context of the development of digital problems is presented. The necessity of using economic and mathematical methods embedded in digital technologies to support decision-making in the management of public finances is substantiated. It is shown that territorial budgets play a key role in the system of public Finance. It is argued that due to the conjunctural changes in the external environment, the decision-making process for the management of the budget of administrative-territorial units takes place in conditions of uncertainty, which translate the management problem into a class of poorly structured. The solution of this problem required the use of a mathematical apparatus that allows logical analysis of natural language expressions with their subsequent computer processing. The article developed a complex of economic and mathematical models, built on the basis of the theory of formal languages, formal grammars, finite automata, and simulation modeling. The logical-linguistic model of generation and recognition of qualitatively expressed characteristics of the state of the territorial budget represented by natural language lexemes is constructed and implemented by means of the software environment. The simulation model included in the complex interacts with the logical-linguistic model in the process of assessing the state of the territorial budget.**

Keywords— digital economy; economic-mathematical model; formal grammar

I. INTRODUCTION

Currently, a strategically important problem, the solution of which will increase the competitiveness of Russia in the global economic system, is the development of the digital economy as the basis for the creation of new business models, management, relations between economic entities. As you know, digitalization has already entered an active phase of development in the world economy. And the task set in 2017 by the Government of the Russian Federation in the context of the adoption of the program "Digital economy of the Russian Federation" corresponds to the trend of the world economy [1]. The program outlines targets for the transition to a new era of global implementation in the production, management and social processes of cybersystems industry 4.0, the core of which is the information industry. At present, the digital economy is primarily a scientific field. And the results of the study of its problems and prospects become the subject of a thorough analysis of scientists. Scientists have shown that in the current model of socio-economic development of Russia, fundamental changes are needed in the direction of new industrialization. And in the Russian model of industrialization it is necessary to increase the role of state structures. Problems of application of the latest technologies in the context of development of the concept "industry 4.0."the use of digital techniques In total automation of production is devoted to the work of Korovin [4]and N. In. Novikova [5]. Interest in the work of G. Korovin is the author's assessment of the digitalization of the economy in the subjects of the Russian Federation on the basis of the use of various statistical and information models. The author investigates the risks of the Russian industry caused by technological lagging behind the Western countries. In the work of N.V. Novikova deserves attention using the method of evolutionary analysis in the study of the content of the theory of regional economic development. O.A. Romanova's article is devoted to studying of problems of formation of digital economy in Russia [6]. The author of the article on the basis of systematization of new technological trends in the formation of the industry of the world economy proposes ways of development of the industrial complex of the Middle Urals. It is emphasized that in the framework of digitalization there are some problems that need to be solved through the creation of specialized investment technology partnerships. The use of partnership mechanisms in the formation of economic clusters, as key instrument of competition in terms of digitization, dedicated to the research of V. A. Blaginina, E. L. Plisetsky, Yu. N. Shedko, S. I., Coberci, N. To. Vasilyeva, V. V. Prokhorova, A. A. Adamenko, V. A. Tupchienko, S. A. Related, B. A. Blaginina, Shkurkina V. D., S. S., Shestopal, L. K. Gurieva, V. A. Guryanov, D. V. Shiryaeva, I. L. Litvinenko, N. V. Rubtsova, E. N. Zakharova [7,8,9,10]. The works proved the effectiveness of the cluster approach as the future in building the digital economy of Russia. It is shown that the concept of economic clusters creates favorable conditions for the creation and implementation of advanced digital technologies in Russian production. Methodological approaches to the assessment of the penetration of digital technologies into the Russian economy developed in the studies of V. V. Akberdina [11], which prompted theoretical research platform of the digital transformation of the economy on the basis of the theory of the creation of a new industrial society on the principles of synergetics. The stages of transformation of the industrial complex are modeled in the form of a pyramid. The proposed author's method implies a high degree of computerization of industrial enterprises within the framework of digital interaction with suppliers and consumers. Thus, the process of digitalization involves the transfer to the digital environment of all aspects of the activity, previously performed by man. The foundation of digital transformation is the use of mathematical modeling methods to support management decisions in all areas of activity. At the same time, in the creation of mathematical models, there is a trend towards the application of artificial intelligence methods, which make it possible to build computer algorithms for formulating conclusions according to the accepted rules of inference. The digital economy unlocks a wide range of opportunities for improving public administration. Modern digital technologies form a high-tech environment for a digital public administration platform that ensures the effectiveness and soundness of decisions taken in managing public finances. In this regard, the task of creating new technologies of public administration with built-in economic and mathematical models in the framework of the formation and development of the digital economy is of particular importance. Public Finance plays a leading role in the public sector. The article proposes a model tool to support decision - making in the management of public Finance, developed on the basis of the methodology of system modeling. The basis of system modeling is the use of information at the verbal level. Developed on the basis of convergence theory of formal grammars, formal languages and simulation modeling modeling tools has the property of interactive communication with the user in natural language.

II. THE CONSTRUCTION OF MATHEMATICAL MODELS

In matters of managing public finances, the task of assessing the balance of the budget in the planning period is of particular importance. The solution to this problem is based on the results of forecasting budget flows using a mathematical apparatus that uses deterministic or stochastic methods. But the application of these methods requires representative samples to estimate budget revenues and expenditures. As a result of the changes in the economy caused by fluctuations in the external environment and the lack of a sufficient number of clear statistical data on budget revenues and expenditures, decision-making takes place in conditions of uncertainty. In such situations, management personnel often make decisions, guided by their own intuition and using qualitatively defined characteristics that are expressed verbally in the form of natural language sentences. In this regard, in the construction of economic and mathematical models there is a need for the use of calculus, which is the basis for the interpretation of natural language. The authors of this article propose a logical-linguistic model for the formal description of budget flows, which allows to generate sentences of natural language in the form of compound terms on the basis of the formal grammar. Therefore, for the formal description of qualitatively expressed budget characteristics, a mathematical construct is used, such as a linguistic variable $< X, T(X), U, G, M >$, in which the variable X identifies the name of the linguistic variable, $T(X) -$ values of the linguistic variable, which are natural language words as a set of atomic terms. Atomic terms play the role of names of fuzzy sets, reflecting the qualitative characteristics of revenues and expenditures of the budget for a given universal set U . The structure of the linguistic model includes formal grammar G for generating natural language sentences from the original atomic terms $T(X)$, as well as a set of semantic rules $M = \{M_{t_i}\}$ for translating verbal descriptions obtained by the rules of formal grammar into their quantitative characteristics in the form of fuzzy sets. The generating grammar G, as a syntactic rule, is described by a tuple $G =< V_T, V_N, \delta, P >$, the components of which are the basic terminal $V_T = \{a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8, a_9\}$ and nonterminal $V_N = \{\Psi_1, \Psi_2, \Psi_3, \Psi_4\}$ alphabets, the initial symbol of the grammar $\delta \in V_N$, which is its axiom, and a set of inference rules $P = \{\tilde{\Psi}_i \to \tilde{u}_i / i = \overline{1,k}\}$ that allow, as a result of substitution operations, to generate composite terms, as logical constructions from the following letters of the terminal alphabet V_T : $a_1 = very$; $a_2 = large$; $a_3 = quite$; $a_4 = not$;

$a_5 = small$; $a_6 = average$; $a_7 = and$; $a_8 = or$; $a_9 = substantially$. Moreover, the terminal alphabet V_T is represented as the union of subsets of atomic terms $T_a = \{a_2, a_5, a_6\}$ and subterms $T_P = \{a_3, a_4, a_7, a_8, a_9\}$.

The inference rules that generate compound terms from atomic ones are the following expressions:

$$P_1 : \delta \to a_2 ;\ P_2 : \delta \to a_1 \Psi_2 ;\ P_3 : \Psi_2 \to a_2 ; \quad (1)$$

$$P_4 : \Psi_1 \to a_1 \Psi_2 ;\ P_5 : \delta \to a_3 \Psi_2 ;\ P_6 : \delta \to a_4 \Psi_2 ; \quad (2)$$

$$P_7 : \Psi_2 \to a_4 \Psi_3 ;\ P_8 : \Psi_3 \to a_2 ;\ P_9 : \Psi_2 \to a_5 ; \quad (3)$$

$$P_{10} : \Psi_3 \to a_5 ;\ P_{11} : \Psi_2 \to a_6 ;\ P_{12} : \Psi_3 \to a_6 ; \quad (4)$$

$$P_{13} : \Psi_2 \to a_2 \Psi_4 ;\ P_{14} : \Psi_4 \to a_7 \Psi_2 ;\ P_{15} : \Psi_4 \to a_8 \Psi_2 ; \quad (5)$$

$$P_{16} : \Psi_1 \to a_9 \Psi_2 ;\ P_{17} : \Psi_3 \to a_1 \Psi_3 ;\ P_{18} : \delta \to a_5 ; \quad (6)$$

$$P_{19} : \delta \to a_6 ;\ P_{20} : \Psi_2 \to a_3 \Psi_2 . \quad (7)$$

The given production rules allow to generate compound terms with the help of a system of conclusions. For example, compound terms "very large" and "very small" are generated by the following output systems:

$$\underset{\uparrow P_2}{\delta} \underset{G}{\Rightarrow} a_1 \underset{\uparrow P_3}{\Psi_2} \underset{G}{\Rightarrow} a_1 a_2 ; \qquad \underset{\uparrow P_2}{\delta} \underset{G}{\Rightarrow} a_1 \underset{\uparrow P_4}{\Psi_2} \underset{G}{\Rightarrow} a_1 a_1 \underset{\uparrow P_3}{\Psi_2} \underset{G}{\Rightarrow} a_1 a_1 a_2 . \quad (8)$$

Compiled inference rules allow us to derive more complex compound terms, for example, "not very big and not very small":

$$\underset{\uparrow P_6}{\delta} \underset{G}{\Rightarrow} a_4 \underset{\uparrow P_4}{\Psi_2} \underset{G}{\Rightarrow} a_4 a_1 \underset{\uparrow P_{13}}{\Psi_2} \underset{G}{\Rightarrow} a_4 a_1 a_2 \underset{\uparrow P_{14}}{\Psi_4} \underset{G}{\Rightarrow} a_4 a_1 a_2 a_7 \underset{\uparrow P_7}{\Psi_2} \underset{G}{\Rightarrow}$$
$$\underset{G}{\Rightarrow} a_4 a_1 a_2 a_7 a_4 \underset{\uparrow P_{17}}{\Psi_3} \underset{G}{\Rightarrow} a_4 a_1 a_2 a_7 a_4 a_1 \underset{\uparrow P_{10}}{\Psi_3} \underset{G}{\Rightarrow} a_4 a_1 a_2 a_7 a_4 a_1 a_5 . \quad (9)$$

Thus, the constructed grammar G generates a formal language $L(G)$. In order to formally describe an infinite set of words in the language $L(G)$, a regular expression is constructed, which allows to solve the problem of algorithmization of the language $L(G)$ and its further software implementation:

$$\Psi_1 = a_1(a_1 + a_3 + a_2 a_7 + a_2 a_8)*(a_4 a_1 *(a_2 + a_5 + a_6) + + a_2 + a_5 + + a_6) + a_3(a_1 + a_3 + a_2 a_7 + a_2 a_8)*(a_4 a_1 * *(a_2 + a_5 + a_6) + a_2 + + a_5 + a_6) + a_4(a_1 + a_3 + a_2 a_7 + + a_2 a_8)*(a_4 a_1 *(a_2 + a_5 + a_6) + + a_2 + a_5 + a_6) + a_2 + + a_5 + a_6 . \quad (10)$$

To solve the problem of word recognition in a given grammar, an algorithm is created that allows to determine the belonging of a compound term to the constructed language $L(G)$. At the same time, the mathematical abstraction "formal grammar G" is matched with the mathematical construct "finite automaton $R =< Q, A, q_1, F, q_4 >$" with a set of states $Q =< q_1, q_2, q_3, q_4, q_\varphi >$ and a finite input alphabet. The set of states of a stochastic automaton is bijectively correlated with the set of non-terminal symbols of a formal grammar G: $q_1 = \Psi_1$; $q_2 = \Psi$; $q_3 = \Psi_3$, $q_4 = \Psi_4$. The transition function $F : Q \times A \to Q$ of the state machine is represented by table 1. Table 1 demonstrates the isomorphism of the mathematical constructs of formal grammar $G =< V_T, V_N, \delta, P >$ and finite automaton $R =< Q, A, q_1, F, q_4 >$. Indeed, the automaton performs a transition from state q_i to state q_j under the action of an input signal a_k, which corresponds to the output rule $q_j \to a_k q_i$. This gives the right to conclude that the constructed finite automaton R perceives those and only those chains of symbols that belong to the formal language $L(G)$ generated by the formal grammar G.

TABLE I. STATE TRANSITION $F : Q \times A \to Q$ FUNCTION

Conditions of the automatic machine	The input alphabet								
	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
q_1	q_2	q_4	q_2	q_2	q_4	q_4			q_2
q_2	q_2	q_4	q_2	q_3	q_4	q_4			
q_3	q_3	q_4			q_4	q_4	q_2	q_2	
q_4							q_2	q_2	

The transition function $F : Q \times A \to Q$ of the machine is implemented programmatically. The program interface is shown in figure 1.

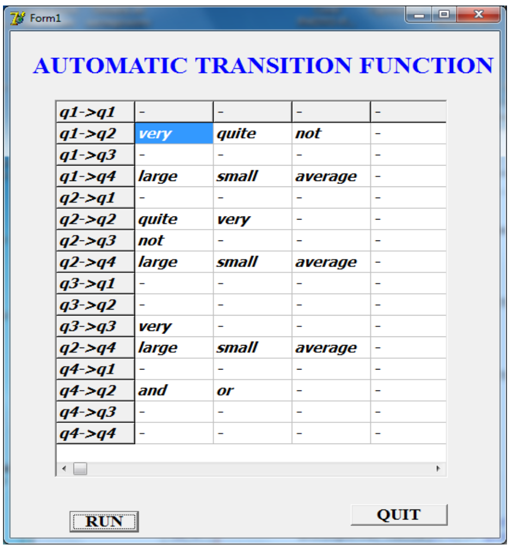

Fig.1. Compound term recognition program interface

If the input of the machine R is supplied with a chain of symbols from the area of permissible symbols $a_{i1}, a_{i2}, ..., a_{ik}$ of the formal language $L(G)$, the machine reaches the final state and stops. This symbolizes the fact that the machine has accepted the chain $a_{i1}, a_{i2}, ..., a_{ik}$. Otherwise, the machine gives an error. For further processing of the chain $a_{i1}, a_{i2}, ..., a_{ik}$, which is a verbal description of the state of budget revenues and expenditures, a semantic rule has been developed that translates these characteristics into fuzzy sets for the purpose of computer processing. These fuzzy sets are used in a simulation model for estimating and predicting the state of the budget. The general view of the interface of the software implementation of the simulation model is presented in Figure 2.

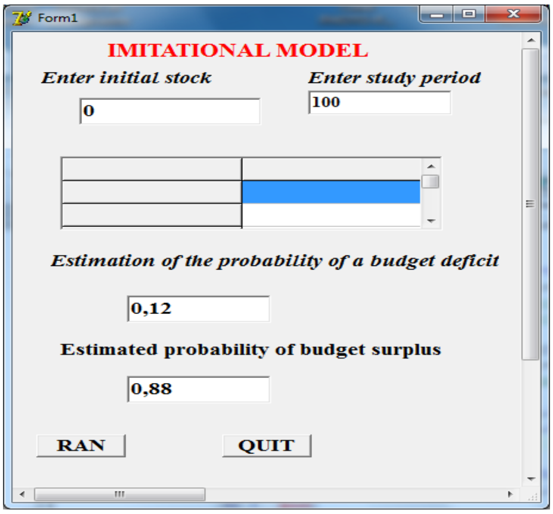

Fig.2. Simulation model interface

In the simulation model, the input values are tax and non-tax revenues, as well as budget expenditures, which are formally described by stochastic or linguistic variables. The simulation model determines the value of estimating the probability of deficit and budget surplus during the planned period. The value of the planned period is set interactively.

III. PRACTICAL SIGNIFICANCE

The practical significance of the research is the inclusion of the developed model tools in the technological chain of solving problems of budget management. The created software tools allow to give a quantitative assessment of the made managing decisions in the conditions of stochastic and linguistic uncertainty.

The processes of exponential growth of information flows inspired the question of creating a new type of economy, in which the dominant value is the use of the potential of technologies for the synthesis of mathematical modeling with artificial intelligence. The proposed complex of economic and mathematical models is the result of such synthesis, in which the simulation models use formalized knowledge of management personnel about the characteristics of the object, expressed in verbal form. The constructed economic and mathematical models received the software embodiment.

IV. DISCUSSION OF RESULTS

The article concludes that the development of the digital economy is currently a key factor in economic growth. The formulation of this problem corresponds to the trends of the world economy. The analysis of the problems of digitalization as a scientific direction aroused wide interest of scientists in various fields of activity. In modern researches the set of ways of formation of the Russian economy in the direction of digital transformation is offered. In this aspect, the strengthening of public finances through the creation of a digital platform becomes a strategic task. The proposed in this article economic and mathematical tools designed to support decision-making on the management of the territorial budget, allows you to quantify the state of the budget in the planned period on the basis of processing the knowledge of experienced management personnel.

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