

PAPER • OPEN ACCESS

Information-analytical semantic model of an expert system for studying the co-evolution of the sociotechnical landscape in digital reality

To cite this article: M V Artemenko *et al* 2020 *J. Phys.: Conf. Ser.* **1658** 012002

View the [article online](#) for updates and enhancements.



IOP | ebooks™

Bringing together innovative digital publishing with leading authors from the global scientific community.

Start exploring the collection—download the first chapter of every title for free.

Information-analytical semantic model of an expert system for studying the co-evolution of the sociotechnical landscape in digital reality

M V Artemenko¹, V G Budanov² and N A Korenevskiy¹

¹Department of biomedical engineering, Southwest state university, Kursk, Russia

²Department of philosophy and sociology, Southwest state university, Kursk, Russia

E-mail: artem1962@mail.ru

Abstract. Currently, the development of society is largely determined by the expansion of digital technology into various social practices. Prediction and management of the co-evolution of society in digital reality is determined by the need to ensure sustainable development of society and adequate satisfaction of practices with information technology. The aim of the study was the development and pilot study of the capabilities of the information-analytical semantic model of an expert system for the analysis and management of socio-technical landscapes (STL) in digital reality. The network semantic structure of the knowledge base with unified decision modules in network nodes is substantiated. An enlarged diagram of the model is given and its functioning is described. Examples of the pilot application of the crucial modules of the expert system are examined: social practice “medicine” and digital technologies: “Artificial Intelligence”, “Information Technology”, “Mobile Technologies”, “Internet of Things”, “Big Data”. There are sharp changes in the ratios of feasibility and demand for technologies that occurred in the first half of 2020 compared to 2019 (which is associated with the consequences of the COVIN-19 pandemic). It is shown that the STL reaction is modeled by a transient process characteristic of the vibrational link.

1. Introduction

The development of society in a certain territory in a different environment (industrial relations, historical conditions, technological structures) as a result of synergistic processes, structurally organized socio-technical landscapes (STLs) appear, which belong to the class of open, complex and living systems [1, 2]. In [3], it is noted that the functional state of various STLs, the mechanisms by which they implement target functions at various stages of the life cycle, the trend of co-evolution in the figure of reality, largely determine the stable development of society. There is an urgent problem of developing adequate tools for studying the behavior of STLs, which include various smart expert systems.

The expert systems currently used in the social sphere are highly specialized for certain corporate interests. For the design of expert systems of a universal nature, designers such as: KEE, ART, EXSYS, GURU [4] are used. The accumulated experience in the development and operation of expert systems has led to the emergence of certain theoretical concepts of the structure and functioning of the social expert system (S.N. Makarov, E. Fegerbaum) and the development of convergent interactive tools for visualizing a variety of information. For example, the online platform DEFTECH VISION 2015, developed by the virtual research institute Envisioning272, presents to the researcher on the monitor a



multidimensional space of indicator characteristics and interconnections that characterize modern technologies [5].

Meanwhile, it is noted that the existing expert systems in the social sphere are highly localized in nature, aimed at solving specific problems, and do not work effectively in case of changing conditions. They do not have the stability of functioning in time with a rapidly changing environment (*umwelt*) (E.L. Loginov, I.D., Eriashvili, A.P. Demichev, V.A. Ilyin, V.A. Yashchenko, V. Viljans, N. Taleb), Convergent mathematical apparatus (for example, the "algebra of conscience" by V. A. Lefebvre [6]) is practically not used. In addition, the creation of expert systems for studying STL is complicated by the formation of representative training samples due to the almost impossible observance of the rule for repeating a situation (experiment) in accordance with the phenomena of the arrow of the time Prigogine [7] and The Black Swan (N. Taleb) [8].

It should be noted that in the last decade there has been an intensive development of the means of Internet communications of social networks (A.M. Leshchenko, V.A. Pleshakov, V.M. Sazonov, K.O. Chernyaeva and others). Since communications provide adequate internal and external control of the system, during the deformation of traditional means of communication between the elements of society, when destructive states of Internet communication arise, they essentially create a fourth signaling system. This allows the destructive state not to go into a pathological, and, subsequently, to the end of the life cycle of one STL or the emergence of a new structure (the birth and evolution of a new STL) [9]. An example is structural deformation caused by natural disasters, pandemics, natural disasters, wars. The development of network communications leads to the intensification of the capabilities of information technology. This leads to the fact that the structures of expert systems are modified due to the appearance of a new functional module in them, which ensures the integration of various characteristics of digital reality obtained as a result of applying Data Mining technologies to Big data and methods for processing weakly structured, heterogeneous, and weakly defined information. The role of taking into account the peculiarities of the existence of societies of various hierarchical strata under the conditions of both a digital attitude and digital interaction and possible corrective control of the surrounding and inner worlds is growing [10]. The focus of existing expert systems on solving specific problems, of course, simplifies their development, but does not allow them to function effectively when solving strategic problems of the development of societies in digital society, affecting the life cycles of such systems.

Thus, despite the large number of studies in the field of using the achievements of artificial intelligence to analyze and predict the development of societies, the development of a methodological base for creating an expert system that allows analyzing a large number of digital reality parameters using convergent methods of the humanities and natural sciences is an actual scientific and technical problem.

One of the ways to study the interaction of digital technologies and social practices of modern society is the methodology of sociotechnical landscapes (STL) [11, 12]. The methodology is based on the study of the statics and dynamics of trajectories of indicator variable profiles (indicators, STL characteristics) that determine the co-evolution of taxa lying in cells formed by the Cartesian product of many social practices (one coordinate axis) and digital technologies (second coordinate axis).

An analysis of literary sources and our own studies have shown that the relationships between indicators are poorly formalized, dynamic, and fuzzy. This does not allow the effective use of traditional mathematics methods, including mathematical statistics. Experience in solving such problems shows that the most effective tool for describing and analyzing such data structures is expert systems, the knowledge bases of which interact with the user through the corresponding semantic models (networks) [13]. The backbone component of the expert system is the knowledge base. The development of an information-analytical semantic model (knowledge base) of an expert system specializing in the study of the behavior of the socio-technical landscape was the aim of the study.

2. Results and discussion

An analysis of the problems solved using models of sociotechnical landscapes made it possible to select a network model as the model of the knowledge base, based on the following. Target functions or other indicators characterizing the development of STL in digital reality are formed on any combination of social practices and digital technologies and are measured on various scales. The most typical indicators include: intensity, tension, feasibility, relevance, effectiveness, sensitivity, effectiveness, reactivity, activity, passivity, reflectivity, prognosticity, noise immunity, functional stability, autopoiesis, auto-control, synergetism. The boundaries between social practices and digital technology are very arbitrary. Social practices complement and interact with each other (for example, health determines the success of solving the problems of education and sociology). Digital technologies interact and develop each other (for example, Big Data technologies expand the capabilities of neural network technologies and vice versa). At each stage of research, the hypotheses put forward are confirmed, refined, and verified on various branches and paths of a graph of some network managed at the next hierarchical level [2, 14]. The proposed semantic network is, as it were, superimposed on the STL ontology network. The co-organization (self-organization processes) of the network is described quite well if we rely on the ideas of quantum-synergetic anthropology developed by one of the co-authors [15, 16]. This theory combines the methodology of synergetics and the quantum approach, allowing us to describe complex developing hierarchical systems.

In this regard, it is proposed to put the semantic network [13, 17] as the basis for the functioning of the corresponding expert system. Figure 1 shows an enlarged diagram of the information-analytical semantic network model of the knowledge base of the expert system for studying the evolution of STL in digital space, which reflects the topological structure of the STL.

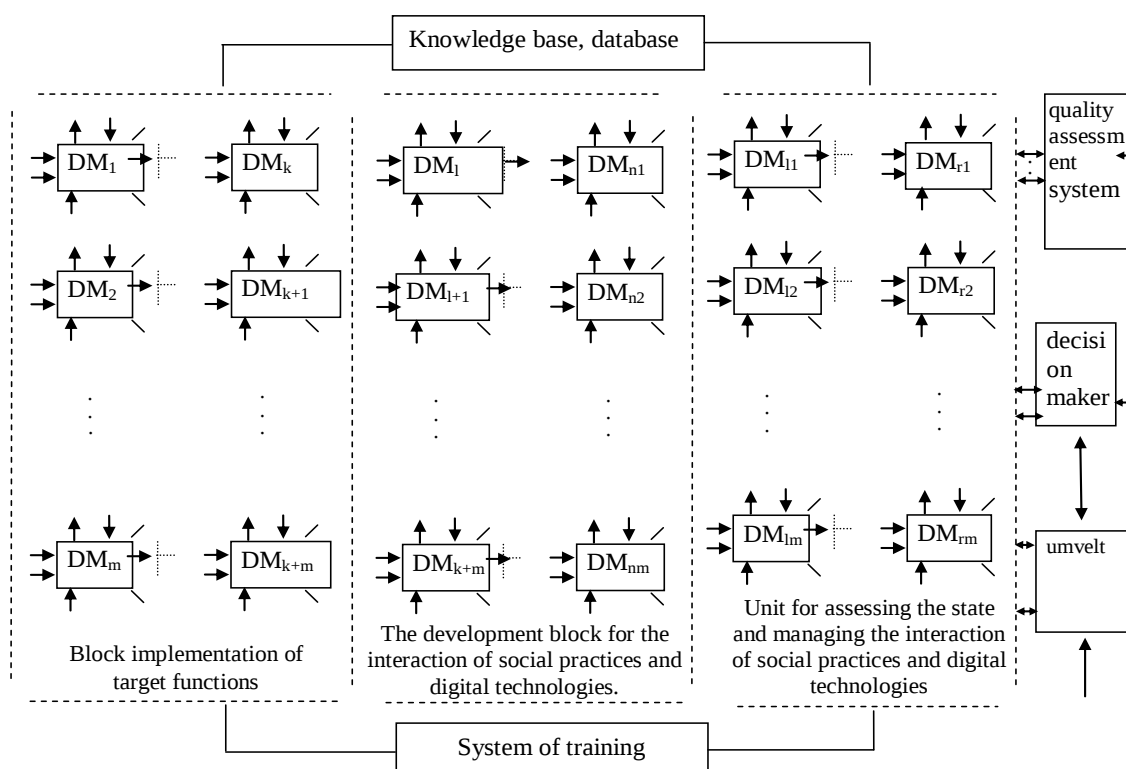


Figure 1. It is information analytical network semantic model of an expert system.

The implementation block of the objective functions determines the quantitative values of the selected targets for all informative signs, describing social practices and digital technologies (rows) and levels of analysis (columns) of the network (in the nodes of which are unified decision modules – DM).

Each DM is focused on solving specific problems, and therefore its indices (row and column numbers) clearly define the function implemented by the decision module. Each DM is characterized by a vector of weight coefficients, the values of which determine the “importance” of use in solving a certain problem. The procedures that are implemented in the module, for example, include: discriminant analysis, construction of piecewise linear and nonlinear separating surfaces, the formation of Bayesian decision rules, algorithms such as FOREL and KRAB, production rules with clear or fuzzy inference, dynamic interactive construction of two-dimensional mapping spaces, the method of group accounting of arguments, separation from informative signs, symptom complexes, latent variables, the formation of linguistic variables, the Lee method and others. The solver module has several input and output interfaces: for input / output of data, decision rules, addresses, control and training information. The I1 interface provides the transfer to DM of signs describing the studied social practices and (or) digital technologies, and information from other DMs. Using the I2 interface, the conditions of use and operating modes of the DM are determined. Using the I3 interface, queries to the knowledge base are organized, both in statics and in tracking mode. Via the I4 interface, bootstrap of the DM is performed. The I5 interface provides the transfer of the results of decisions made by the DM. The I6 interface generates control information for other DMs at the address received via the I5 interface. The training information that corrects the decision rules is transmitted to the module via the I7 interface.

DM additionally implement the following functions:

- 1) analysis of input information for its completeness and representativeness;
- 2) the organization of the request for additional, clarifying information;
- 3) calculation of reliability indicators of the decisions obtained;
- 4) obtaining several options for alternative solutions;
- 5) the choice of optimal tactics at each stage of the analysis of the interaction of digital technologies with the studied social practice;
- 6) the organization of the recording of facts and data characterizing the co-evolution of social practices and digital technologies;
- 7) the implementation of a mechanism for explaining the reasons for the decline in the quality of decisions made and indicating a possible reason for the decline;
- 8) the implementation of the tracking mode for the list of dynamic parameters, when a list of dynamic tracking parameters is assigned to test hypotheses, and also determines the interval of measurement of parameters and the number of measurements;
- 9) the organization of the adaptive retraining regime in order to improve the quality of decisions.

The choice of the DM module for its inclusion in the semantic network is carried out: either by an expert on keywords; either automatically (in interactive mode); automatically (according to a given algorithm). The choice of types and volumes of tasks implemented by the DM is carried out by a cognitologist. At the same time, the amount of information selected by the DM should be, on the one hand, not large in order to ensure an acceptable speed of the system, and on the other hand, to have functional completeness, ensuring the requirements of good interpretability.

The analysis unit for the development of the interaction of social practices and digital technologies (figure 1) provides the solution to the following tasks:

- the formation and interpretation of targets in the language of the subject area;
- forecasting the results of the interaction of digital technologies with social practices;
- implementation of the review of facts and data, allowing to evaluate the dynamics of interaction and mutual influence of social practices and digital technologies;
- dynamic tracking of the results of the interaction of digital technologies with social practices.

Calculation of quality indicators characterizing the interaction of the researcher with the expert system, for example, with the aim of forming tips with incorrect actions of experts.

The unit for assessing the state and managing the interaction of social practices and digital technologies (figure 1) solves the following tasks:

- formation of recommendations in the language of the subject area on corrective and control actions in order to optimize the interaction of digital technologies with social practices;
- identification of possible negative trends from the interaction of digital technologies with social practices with a mechanism for dynamically monitoring the quality indicators of such interaction;
- documentation of the results of the interaction of digital technologies with social practices;
- calculation of quality indicators of corrective actions.

As a result, DM forms an ensemble of alternative hypotheses with the corresponding values of confidence coefficients. To confirm or exclude the hypotheses put forward, DM requests additional information. If none of the hypotheses provides a solution better than a certain threshold of confidence, then the transition to a new DM is either in-depth (refinement or development of a version of the selected hypothesis), or in breadth (transition to a new hypothesis), or backward if the hypotheses originally put forward are not true.

When working with the network model, the application path of the DM is fixed in a special buffer memory. This allows you to trace the stages and the entire course of the implementation of the investigated processes. Since for each module its weight in making one or another decision is known, and the role and weight of each feature used by the DM is also known, it becomes possible to assess the quality of the expert system. The quality control function of the expert's activity is performed by special software tools of the quality assessment system (QAS) (figure 1). The logic of the QAS is based on the fact that more significant, from the point of view of the selected criterion, DM or signs are not involved (not analyzed). When working in automatic mode, the transition from one DM to another is carried out along the highway with maximum confidence coefficients, implementing, for example, a dynamic programming algorithm.

It should be noted that the separation of tasks and functions across the DM network makes it possible to simplify the task of finding those RMs that lead to errors in the expert system. As soon as the number of errors made by the DM reaches a threshold value, an adaptive retraining training system is connected to this module, which corrects the corresponding decision rules and (or) connections.

As a verification of the capabilities of the proposed semantic network of the expert system, the problem of exploratory analysis in taxons "medical practice - digital technologies" of indicators characterizing the feasibility in social practice i of digital technology j (Sd_{ij}) and the demand for digital technology j by social practice i (Ds_{ij}). The values were estimated using the technique described in [18]. Figure 2 shows: in the left column - the dynamics of publications in Google Scholar on research in medical practice, in the top row - the dynamics of publications in various digital technologies (and a two-year forecast), in a taxon - feasibility and relevance in taxa of the STL fragment under consideration in 2019 and the first half of 2020 (characterizing the COVID-19 pandemic), the use of decision modules of the proposed expert system made it possible to construct and calculate the predicative functions of various classes of structures (a fragment is given in table 1), and to calculate the indicators of feasibility and relevance.

The table shows the results of DM's work on the structural and parametric identification of the following models polynomial time dependence:

- parabola, fourth and sixth degrees (Pol2, Pol4, Pol6); exponential (Exp);
- exponential harmonic (ExpGarm) $x(t)=C_0+\sum(C_1 \cdot \exp(k_i \cdot t) \cdot \sin(w_i \cdot t + \phi_i))$;
- exponentially harmonic absolute (ExpGarmA) $x(t)=C_0+\sum(C_1 \cdot \exp(k_i \cdot t) \cdot |\sin(w_i \cdot t + \phi_i)|)$;
- bell-harmonic (Exp2Garm) $x(t)=C_0+\sum(C_1 \cdot \exp(k_i \cdot t^2) \cdot \sin(w_i \cdot t + \phi_i))$;
- bell-harmonic absolute (Exp2GarmA) $x(t)=C_0+\sum(C_1 \cdot \exp(k_i \cdot t^2) \cdot |\sin(w_i \cdot t + \phi_i)|)$;
- dynamics equations (EqDim) in operator form $T^2p+2s \cdot Tp+1=0$;
- according to the formula $S(t)=F(S(t-1), S(t+1))$ - (SRP1).

The monitoring results were divided into two subsamples - training and examination. At the first, structural and parametric identification of models was carried out; on the second, the quality of the constructed models was monitored by exceeding the value of the determination criterion R^2 of the threshold level corresponding to $p = 0.01$ ($R^2_{por} = 0.43$).

This allowed, in particular, the following conclusions:

1) A sharp change in trends in taxa begins around 2011-2013 (from a smooth rise to exponential growth). This is caused by the following: firstly, the first official statement on the transition to Industry 4.0 was made in Germany in 2011, and secondly, publications in print, as a rule, have 1-2 year “delays” associated with the procedures for preparing a publication for publication.

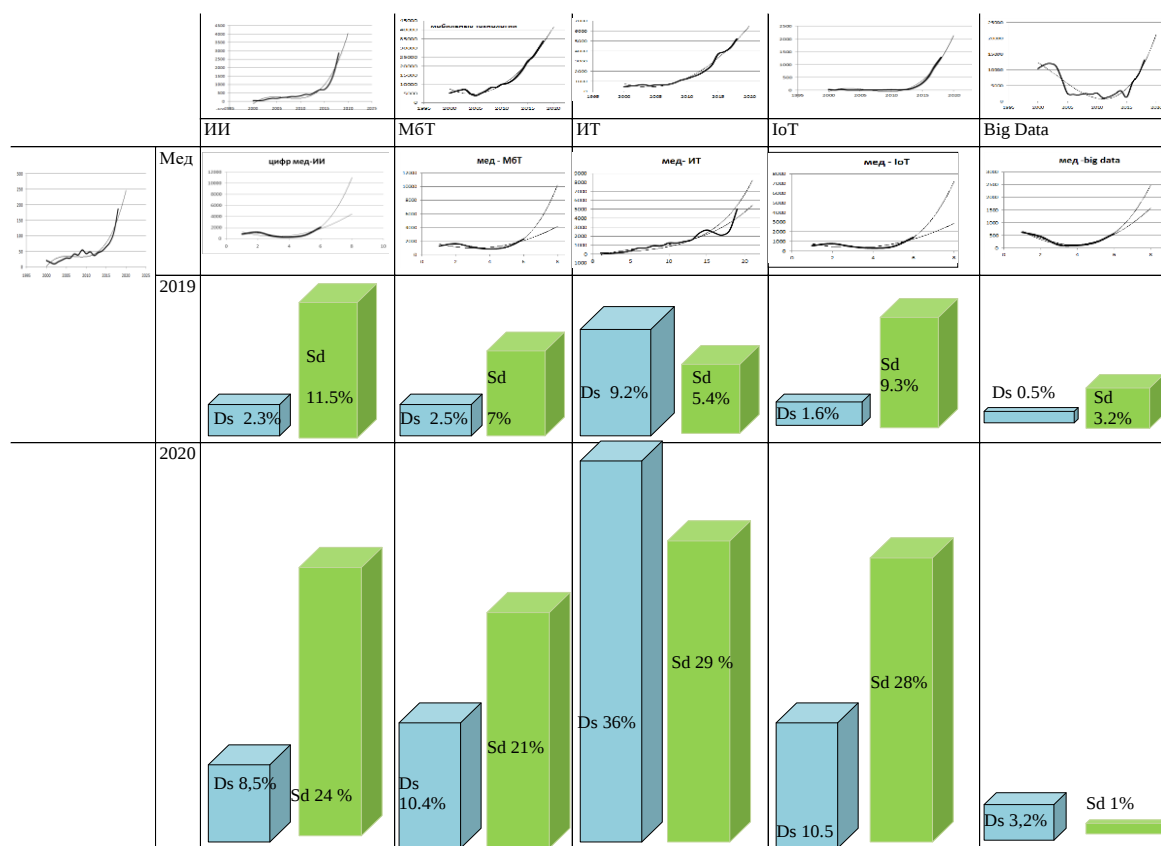
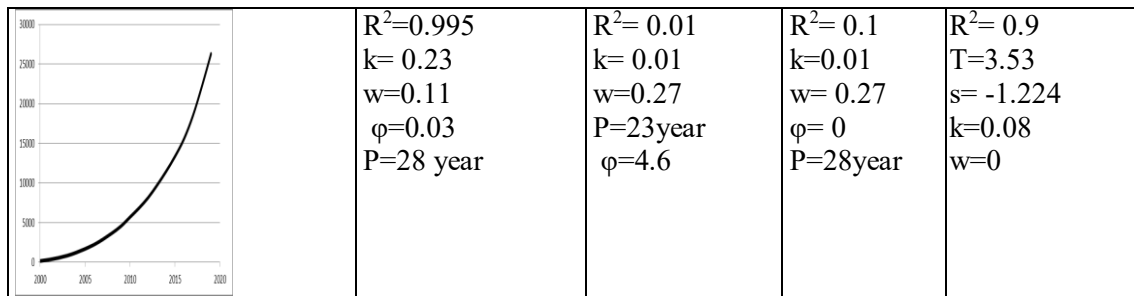


Figure 2. STL on social practice medicine (fragment).

Table 1. Predicative functions in a taxon “Medicine – Artificial intelligence”.

Temporal trend x	Pol2,4,6	Exp	SRP1	expGarm
	$R^2_2=0.99$ $R^2_4=0.9998$ $R^2_6=0.9999$	$R^2=0.995$ $k=0.23$	$R^2=0.999$	$R^2=0.99$ $k=0.23$ $w=0.11$ $P=57$ year $\phi=0.06$
	ExpGarmA	Exp2 Garm	Exp2 GarmA	EqDim



2) In the first half of 2020, there is a sharp change in the “feasibility” and “demand” relations towards a decrease in the relative difference between them; the exception was the Big Data technology, the marketability of which clearly began to lag behind demand. These processes are clearly caused by the needs of medicine for fast and effective means of intellectual digital support during the fight against the COVID-19 pandemic. Information and digital technologies responded well to this “challenge” in decision-making support, but they clearly lagged behind the many-fold increased need for medicine (about 6 times) at that time in the processes of primary accumulation and processing of a large amount of various information.

3) Models like EqDim showed good adequacy. In particular, the model obtained: $3,5 \frac{d^2 x(t)}{dt^2} - 8,6 \frac{dx(t)}{dt} + x(t) = e^{0,23 \cdot t} \cdot \sin(0,11 \cdot t + 0,03)$. We note that it corresponds to the transfer function of the vibrational link and confirms Malinetskii's hypothesis about the possibility of describing processes in society by a second-order differential equation [19].

4) The obtained models allow us to assume the cyclic components in the process under consideration: the demand for artificial intelligence systems in medicine is 9-12-28 years old, which corresponds to the Kitschin and Zhuglar cycles previously identified in STL behavior in [18].

In general, for the processes under consideration, the most adequate should be considered not only parabolic functions characteristic of the early stage of registration, but unified, for which the rest considered are a special case:

$$a \frac{d^2 z(t)}{dt^2} + b \frac{dz(t)}{dt} + z(t) = e^{k \cdot t \cdot |\sin(\omega_1 \cdot t + \varphi_1)|} \cdot (c \cdot \sin(\omega_2 \cdot t) + d \cdot \cos(\omega_2 \cdot t)) + l \cdot t, \quad (1)$$

where: $z(t)$ is the analyzed indicator; $a, b, c, d, k, l, \omega_1, \omega_2, \varphi_1, \varphi_2$ - model parameters.

Thus, we can assume that the behavior of STLs in digital reality is modeled by the reaction to digital reality of a certain vibrational unit (figure 3), which includes two capacitors, two resistors, and inductance. The first capacitor (connected in series) simulates an increase in response in the case of an increase in the frequency of exposure to digital reality in the STL Umwelt. The second capacitor (connected in parallel) models the internal conservatism of the functioning of the STL and provides a protective reaction with increasing frequency of exposure. Inductance, included in series, characterizes the delay of the reaction. Resistors included in both parallel and serial branches simulate the "vitality" of STLs, the convergence of the reaction transition process to attractors (including bifurcation points), and time constants characterizing the transition process as a whole.

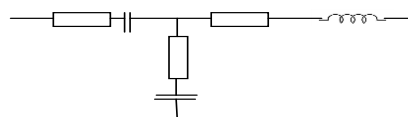


Figure 3. Electric model of reaction of STL.

3. Conclusion

The proposed information-analytical semantic model of the knowledge base differs from previously used in the construction of expert systems for studying self-organizing processes in the behavior and reaction of society to the expansion of digital reality. The differences are as follows:

- conceptual – in the application of the methodology for the presentation and description of the sociotechnical landscape in the context of co-evolution with digital reality in the form of a taxonomic matrix, which allows to unify the synthesis and analysis of various prognostic functions with differentiation of studies on different taxa;
- structural-logical – in the application of the network structure of unified decision modules (with different interfaces) in the nodes of the network model of the knowledge base of the expert system, which allows you to build graphs of decision-making decision trees, organizing the functioning of decision modules both inside and between taxa, taking into account synergetic and interacting processes in STL on various social practices and digital technologies.

A pilot analysis of the possibilities of the proposed semantic model suggests the prospect of its use in the design of the corresponding smart expert systems.

Acknowledgments

Work is performed with assistance of Grant by RNF no. 19-18-00504.

References

- [1] Budanov V G et al. 2019 Sociotechnical landscape in the context of digitalization: the problem of the concept and research methodology *News of Southwestern State University. Series: Economics. Sociology. Management* **9.3** 213–225
- [2] Artemenko M and Korenevsky N 2019 Pilot Study of Representation and Simulation of Differential Ontologies and Basic Principles of Temporal Observability of Evolution of Digital Reality of Social-Technical Landscapes, *Vision 2025: Education Excellence and Management of Innovations through Sustainable Economic Competitive Advantage. Proceedings of the 34th International Business Information Management Association Conference (IBIMA) 13-14 November Madrid, Spain*
- [3] Arshinov V I and Budanov V G 2019 Ontologies and the risks of digital technology: on the issue of representing the socio-technical landscape *Complexity. Mind. Postclassic* **2** 51–60
- [4] Chuvikov D A and Peterson A O 2016 Comparative analysis of instrumental environments for the development of expert systems in various subject areas *Industrial Automated Control Systems and Controllers* **8** 20–27
- [5] https://www.researchgate.net/profile/Quentin_Ladetto/publication/308929622_Defence_Future_Technologies_Emerging_Technology_Trends_2015/links/57f80ec708ae886b89836587/Defence-Future-Technologies-Emerging-Technology-Trends-2015.pdf
- [6] Lefebvre V A 2011 *Algebra of Conscience*, Springer 2011
- [7] Kravchenko S A 2019 The Complicating Dynamics of Russian Sociology: The Effects of the Arrow of Time *Humanities of the South of Russia*, **8.1** 33–55
- [8] Taleb N 2019 *Skin in the Game. Hidden Asymmetries in Daily Life*, Penguin Group
- [9] Artemenko M V and Mayakova A V 2019 Management of the social problems of the expansion of modern digital reality: philosophical, methodological and technical aspects *News of Southwestern State University. Series: Economics. Sociology. Management* **9.4** 216–223
- [10] Pavlikov R and Beisembekova R 2016 Architecture and security tools in distributed information systems with big data, *2016 IEEE 10th International Conference on Application of Information and Communication Technologies (AICT)*, IEEE
- [11] Korenevsky N A, Artemenko M V and Rodionova S N 2019 Socio-technical landscape: soft mapping on the base coordinates of ontological matrices of social practices and digital technologies *Complexity. Mind. Postclassic* **3**

- [12] Chekletsov V V 2019 The Landscape of Russian Digital Philosophy: A Review of the Discussion *Philosophical problems of information technology and cyberspace* **1.6** 88–96
- [13] Wagner W P 2017 Trends in expert system development: A longitudinal content analysis of over thirty years of expert system case studies *Expert systems with applications* **76** 85–96
- [14] Artemenko M V 2020 Sociotechnical landscape: trends of computer technologies and hierarchical string management model *Social space* **6.2** p 1
- [15] Budanov V G 2009 How is quantum-synergetic anthropology possible: synthetic worlds of physicality *Physicality as an epistemological phenomenon* 55–70
- [16] Arshinov V I and Svirsky Y I 2019 The complex world and its observer *Person* **30.2** 130–153
- [17] Albegov E V, Butenko D V and Butenko L N 2014 *Homeostatics: A Conceptual Modeling of Structured Resilient Systems* (Moscow: Publishing House of the Academy of Natural Sciences)
- [18] Arshinov V I, Artemenko M V, Aseeva I A et al. 2019 Sociotechnical landscape of digital reality: philosophical and methodological concept, ontological matrices, expert empirical verification (Kursk)
- [19] Malinetskiy G G 2005 *The mathematical foundations of synergetics* (Moscow)