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# Classification of sociotechnical landscapes on the basis of analogies of cortege codes of indicators

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**Abstract.** Now new technologies within the Industry 4.0 develop. Convergence of various applications of applied mathematics for a research of a synergetic coevolution the sociotechnical landscapes (STL) is intensified. STL is presented in the form of a taxonomical ontologic matrix which elements are symbols of the Cartesian work of sets social the practician and digital technologies. The train of indicator signs which is unambiguously characterizing levels of tension of STL is applied to classification of STL. The method of coding of indicator signs for calculation of value of the qualifier based on calculation of a binary code on function of accessory of each sign which carrier is the natural logarithm of a relative deviation of nominal rate of sign from registered is described. The reversibility of formation of the qualifier allows carrying out decrease in dimension of feature space without information losses. Results of researches STL of Kursk region are given in work (the train was presented by 20 indicators). The conclusion about prospects of application of the considered applied method of the mathematical analysis of the solution of classification tasks is drawn.

## 1. Introduction

The current state of development of society is characterized by intensive introduction of digital technologies in informative and administrative aspects of activity, in functioning of various hierarchical structures providing adequate and optimum existence of society in the environment. Super such technologies as actively develop: Big data and Data Mining, block chain, digital tourism, remote education, digital and telemedicine, digital economy and management, artificial intelligence, search programs, the Internet of things, social networks, computer translators and game programs, digital neuro-linguistic programming, technologies a chat boats, computer modeling in policy and ecology, digital geographic information systems, online stores, etc. [1].

In this regard, in all leading countries of the world the new technological directions of forecasting and management of sociotechnical and socioeconomic systems connected with the Industry 4.0 [2] intensively develop. The happening processes of global digitalization cause convergences of the theory and practical experience, the various directions of applied mathematics for a research of various aspects of a synergetic co-evolution of sociotechnical landscapes [3].

Evolution of information society, finally, finally led to emergence of new essence – a sociotechnical landscape (STL). The increasing trend of scientific research (and as a result, publications), in the field of a research of processes in STL, the formations of sets of the indicator signs characterizing various levels of functional tension of STL and allowing to predict and operate development of STL [3, 4] was defined.



Use of digital technologies for the solution of these tasks causes intensive development of methods of artificial intelligence, the system analysis, applied mathematics and mathematical modeling.

The real, initial stage of studying of STL is characterized by a set of various concepts of STL reflecting various dominants depending on research objectives and author's preferences [5, 6]. In a general sense, we will understand the evolving material object located on certain the geographical territory and limited by the multiple parameter contour formed by two hypersurfaces as STL: one hypersurface is anthropological (technologies and practitioners), the second – welfare, providing the activity (existence and functioning) in the territory by means of internal metabolic processes, a car and external managements (including, digital), internal and external material, energy and information resources and streams for achievement of the main criterion function – extension of term of the existence at the minimum power expenses (including, due to expansion).

The given definition allows to mark out the STL following properties:

1. STL realizes the criterion function by means of power information and material exchanges under control of digital technologies (real and virtual), forming a whole at the level of society and its components, including affordans;
2. STL develops on an arrow of time of Prigozhin I.P. [7], having certain stages of life cycle.
3. STL has the closed borders (contours) which at bifurcation stages of synergetic development are disconnected for change of structures and borders of STL and its components.
4. STL possesses the off-line control forming internal metabolism by means of negative and positive feedback.
5. STL interact among themselves by means of mutually transfer of substance, energy and information.
6. STL is live open system;
7. Development of STL in an arrow of time has difficult wave character: against the background of own cars of the waves aspiring to a certain attractor for optimization and acceptable realization of the criterion function, and having two classes of “drivers of a rhythm” – social and technical, with the external amplitude-frequency modulation realized by means of mechanisms of digital reality and virtuality.
8. Criterion functions of STL generally represent nonlinear superposition (convergence) of a number of target “subfunctions” with the optimization described by model of dynamic programming.

During the geological era of an anthropocene [8] which came in the middle of last century modeling, management and forecasting of development of life cycles of STL is carried out by means of the digital technologies relying on methodology of applied mathematics.

In particular, in the real work questions of the formation and application of the set of indicator signs presented in the form of a train and characterizing certain levels of tension of STL are considered. It allows to observe, distinguish (to classify) states and processes in STL for forecasting and management.

## 2. Results and Discussion

Generally, as the basic description, STL we will represent to present in the form of a structural and ontologic matrix  $SL$ , determined by the Descarte's work of a set significant social the practitioner *of SP* and a set of digital  $DT SL = SP \times DT$  technologies.

Elements of the specified sets are taxons existing in certain timepoints the digital technologies and social practitioners providing maximum on time and the coexistence, minimum on power and information expenses, in the environment.

Feature of STL of the first period of an era of an anthropocene is the expressed interaction of systems of external regulation (by means of modern information digital technologies) and autonomous control systems [9]. It should be noted that bifurcations of this interaction, generally, lead to emergence of effect of “A black swan” [10].

Let's call  $SL$  matrix element – ETOM is an element of a taxonomical ontologic matrix. определение This definition, in our opinion emphasizes that, in this case, the element is understood as some group of indicators (signs) characterizing functioning certain sociotechnical the practitioner (education, health saving, production, optimization of the habitat, medicine, etc.) and some digital technology (Big Data, block chain, telemedicine, digital economy, computer games, etc.)

The signs characterizing features and functioning ETOM, as a rule, have the discrete form of representation (symbolical, including digital, coding of levels or ranges of continuous sizes). Let's designate IT as  $ET_{i,j}$  (where  $i$  - the index of practice,  $j$  - the index of technology).

The initial stage of modeling of STL assumes formation of a set of indicator, most informative signs - a set  $\{IET\}$ . In case of rather long monitoring of STL in initial feature space, allocation of indicators depending on a modality of the registered values, it is offered to carry out by the techniques stated in [11, 12].

However so far, monitoring of STL was not carried out. In this regard, it is offered to form a set  $\{IET\}$  holding expert poll of experts. In case of calculation of numerical values of indicators of informational content, the train  $\{CIET\}$  is formed by ordering of elements  $\{IET\}$  in process of decrease of informational content of signs or frequency of occurrence. At expert poll formation of a train taking into account the generalized opinions of experts is supposed.

At the second stage coding of signs and a train is carried out. As signs, generally, have various modality (including representation in the form of a linguistic variable, the following method of coding of a train is offered.

1. For each indicator sign  $\{CIET\}$  function of accessory  $\mu_i(CIET_i)$  such is synthesized that its local maxima correspond to certain conditions of STL ( $i=1,2,\dots,N$ ,  $N$  - amount of indicator signs).
2. Levels for  $\mu_i(CIET_i)$  are set, CIET applied to coding  $CIET_i$ , and the set of the  $CIET_i$  values coded in a binary numeral system is formed  $CCIET_i$  so that the "next" levels differed no more than one "1" in categories of a code. The formula is for this purpose applied:

$$CCIET_i = \begin{cases} 000, \text{ если } \mu_i(CIET_i) < 0,1 \\ 001, \text{ если } 0.1 \leq \mu_i(CIET_i) < 0,25 \\ 011, \text{ если } 0.25 \leq \mu_i(CIET_i) < 0,5 \\ 010, \text{ если } 0.5 \leq \mu_i(CIET_i) < 0,75 \\ 110, \text{ если } 0.75 \leq \mu_i(CIET_i) < 0,85 \\ 101, \text{ если } 0.85 \leq \mu_i(CIET_i) < 0,95 \\ 111, \text{ если } 0.95 \leq \mu_i(CIET_i) \end{cases} \quad (1)$$

3. The binary code of a train is calculated  $CodCor_2$  по формуле on a formula:

$$CodCor_2 = \overline{CCIET_1 CCIET_2 \dots CCIET_N}.$$

4. The decimal code of a train is calculated:  $CodCor_{10} = BD[CodCor_2]$ , where operator  $BD[ ]$  makes a transfer of a code of the train presented in a binary numeral system, in a code, presented in a decimal numeral system.

In order that each received train was the indicator of a certain cluster (taxon) of conditions of STL, it is necessary that the  $CIET_i$  value corresponded to modal  $i$ -go value of sign in a cluster of conditions of  $j$ . If there is a difficulty in determination of modal value (in case of existence of selection of small volume at a grade level or existence only of one observed example or its absence), then: in the first case it is recommended to apply a method of the given values [13]; in the second, - as modal value available is accepted; in the third, - address opinion of experts - specialists analysts or to cognitologist.

Thus, at a grade level of system of recognition of accessory of STL fortune to a certain cluster we come into a set of unambiguously characterizing codes  $\{\{CodCor_1^{10}, CodCor_2^{10}, \dots, CodCor_K^{10}\}$ , where  $K$  - quantity of clusters of conditions of STL. Let's notice that as the train represents strictly certain following of signs, the considered transformations are reversible functions (by a code of a train values of all its components of signs are unambiguously restored).

Correlation of an observed condition of STL  $SctI^*$  to a certain cluster of  $SctII$  is carried out by calculation of distances of its code of a train of  $CodCor^*$  (in the chosen metrics) to  $CodCor_j^{10}$ , where  $j=1, \dots, K$ .  $SctI^*$  corresponds to that cluster of  $SctII$  to which this distance is minimum with a certain maximum deviation  $\varepsilon_j$ . If it is several those clusters, then this fact is fixed and told the researcher. Let's

call the chosen  $S_{ctl}$  - an analog of the analyzed  $S_{ctl}^*$ . Further the decision on the forecast and charge of  $S_{ctl}^*$  similar taken in  $S_{ctl}$ . is made.

Let's notice that as STL evolves in time,  $S_{ctl}^*$ , generally, is functionality in time. Then the forecast of transition to other state is defined by three temporary characteristics: "last experience" or the previous states in time (in case of accounting of one previous we have Markov process), the current state and a predictive state determined by the internal autonomous system of regulation. Researches on the forecast of behavior of the temporary trends characterizing behavior of cardiovascular system showed essential increase in accuracy of the forecast from "the external observer" in this case [14].

The calculated  $S_{ctl}$  value \* also allows to estimate tension of STL  $H_{ctl}^*$  which is understood as deviation degree from some basic not tension of  $S_{ctl0}$  if that is defined. For this purpose, knowing a code of a train of a basic state  $CodCor_0$ , tension level on a formula is calculated:

$$H_{ctl}^* = \log_2 \left( 1 + \frac{|CodCor^* - CodCor_0|}{CodCor_0} \right). \quad (2)$$

Then, by analogy with the offers stated in [15] it is offered to consider the tension levels presented in table 1.

**Table 1.** Levels of tension of STL.

level No.	Value $H_{ctl}^*$	Degree of tension of the STL regulatory systems
1	$\leq 1.38$	Insignificant, optimum level
2	$\leq 1.62$	Insignificant, normal level
3	$\leq 2.38$	Moderate tension
4	$\leq 2.62$	The expressed tension
5	$\leq 3.38$	Sharply expressed tension
6	$\leq 3.62$	Overstrain
7	$\leq 4.38$	Sharply expressed overstrain
8	$\leq 4.62$	Exhaustion of regulatory systems
9	$\leq 5.38$	Sharply expressed exhaustion of regulatory systems
10	$> 6$	Destruction or self-destruction of STL, termination of life cycle

As the STL qualifier it is offered to use the tension levels presented in table 1 i.e. to use type clusters: "level 1", "level 2" ..., "level 10".

In case the feature space is presented by analog signals, then it is recommended to use the specialized technique of synthesis of decisive productional rules for the solution of problems of classification of STL considered, for example, in work [16].

The stated approaches were approved by STL of Kursk region. The urban saturation, domination defined the enterprises, sociocultural traditions are allowed to mark out presumably in Kursk region 4 STL which are territorially limited by borders of districts of the area of taxons: Central (C), Northwest (NW), Southwest (SW), East (E) [17].

The central landscape includes: town Kursk, regions Kurskij and Oktjabr'skij. Southwest unites 10 regions: Belovskij, Korenevkij, Glushkovskij, L'govskij, Medvenskij, Obojanskij, Pristenskij, Ryl'skij, Solncevskij, Sudzhanskij, Bol'shesoldatskij, Kurchatovskij. 40% territories of the area, 35% of the general and 20% of urban population fall to its share.

Northwest STL covers basins of the rivers Svapa and partially Tuskar in borders regions - Dmitrievskogo, Zheleznogorskogo, Zolotuhinskogo, Konyshevskogo, Ponyrovskogo, Fatezhskogo and Homutovskogo. East area includes the following administrative regions: Gorshechnoe, Kastornoe, Sovetskij, Timskij, Cheremisnovskij, Shhigrovskij, Manturovskij. STL occupies the space of 26% from the territory of the area and 17% of urban population of area live in it.

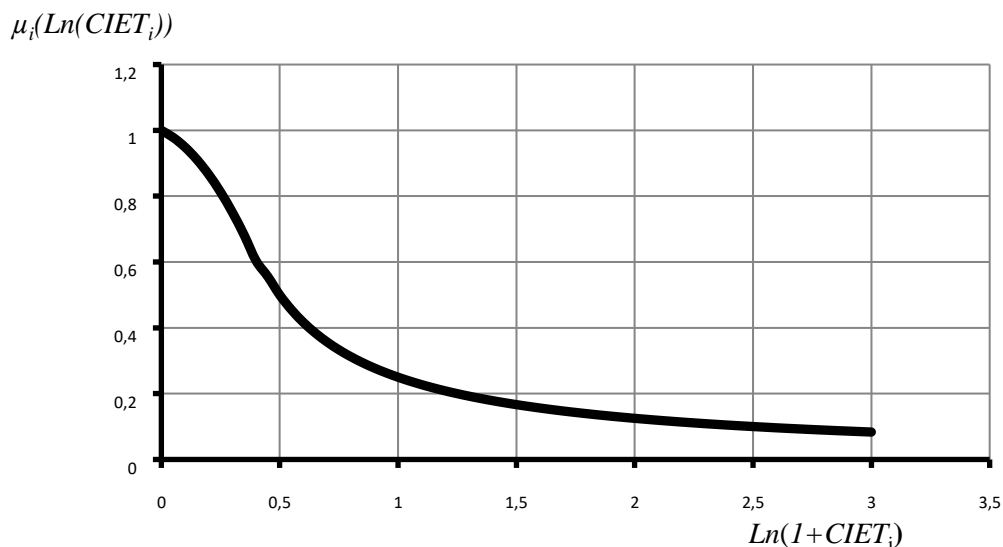
As indicator signs were considered:  $x1$  – population density;  $x2$  – education level;  $x3$  – the level of medical care;  $x4$  – a share of the people occupied in agriculture;  $x5$  – a share of the people occupied in the industry;  $x6$  – pupils at high schools;  $x7$  - pupils in technical schools and schools;  $x8$  - pupils in higher education institutions (living in the territory of STL);  $x9$  – air pollution;  $x10$  – water pollution;  $x11$  – pollution of the soil;  $x12$  – level mortality;  $x13$  – birth rate level;  $x14$  – the level of child mortality;  $x15$  – the level of congenital malformations;  $x16$  - the level of middle age working;  $x17$  – the level of use of Internet and things;  $x18$  – a share of Internet users of networks (social networks);  $x19$  – a share of users personal vehicles;  $x20$  – a share of Internet users of banking.

The specified indicators represented the relative sizes calculated on a formula  $X^* = \left| \frac{X - X_H}{X_H} \right|$  ( $X$  – value of a certain indicator sign in STL,  $X_H$  – nominal rate of sign of  $X$  (the minimum size on group of the chosen and analyzed STL was accepted). Values  $X$  form the corresponding set  $\{CIET_i\}_i$ .

Function of accessory  $\mu_i(CIET_i)$  was received by approximation of the discrete function determined by experts and is calculated on a formula:

$$\mu_i(CIET_i) = \begin{cases} -1.6 \cdot (\ln(CIET_i + 1))^2 - 0.5 \cdot \ln(CIET_i + 1) + 1, & \text{если } \ln(CIET_i + 1) \leq 0.4 \\ \frac{0.25}{\ln(CIET_i + 1)}, & \text{если } \ln(CIET_i + 1) > 0.4 \end{cases} \quad (3)$$

The behavior of this function is illustrated by the schedule submitted in the figure 1.



**Figure 1.** Behavior of function of accessory.

Studying of statistical data on signs of the considered STL in Kursk region allowed to estimate values of signs  $CIET_i$  ( $i = 1, \dots, 20$ ) on which the binary  $CCIET_i$  codes received on a formula (1) were calculated - are presented in table 2.

At the same time the opinion of the group of experts from nine people was used: the sociologist – the doctor of science, philosophers – two doctors of science, the Doctor of Engineering, Candidate of Technical Sciences, Candidate of Biology, the doctor of medical sciences, the demographer, the IT technologies engineer (the coefficient of a concordance of Kendall made  $0.85 \pm 0.03$ ). As a basic class STL “east” was chosen.

The tension of STL calculated on a formula (2) made concerning “east”, respectively: 0.984 for STL “central”, 0.415 – for “Northwest”, 0.386 – for “Southwest”.

**Table 2.** Binary codes of a train of indicator signs of an element of an ontologic matrix  $\{CIET\}$ .

STL Signs	rang	“central”	“Northwest”	“Southwest”	“east”
X3	1	011	101	101	111
X2	2	001	010	110	111
X1	3	001	101	010	111
X18	3	001	110	110	111
X8	4	001	010	011	111
X7	5	011	010	111	101
X6	6	111	111	111	111
X14	7	101	111	101	111
X13	8	101	101	111	110
X17	8	011	010	010	111
X20	8	010	101	101	111
X12	9	101	101	101	010
X19	9	010	111	111	101
X9	10	010	111	101	101
X10	10	110	010	101	111
X11	10	101	010	101	111
X15	10	010	010	110	111
X16	11	101	111	111	101
X4	12	111	101	101	010
X5	12	011	110	110	111
Total decimal code		452945854455306000	769073176406468000	798966578282946000	1152912699835290000

Tensions of the analyzed STL relatively each other are given in table 3.

**Table 3.** Mutual (pair) tension of STL.

STL	“central”	“Northwest”	“Southwest”	“east”
“central”	0.000	0.497	0.519	0.684
“Northwest”	0.764	0.000	0.053	0.415
“Southwest”	0.819	0.055	0.000	0.386
“east”	0.580	0.584	0.529	0.000

The analysis of information provided in tables 2 and 3 allows to draw conclusions:

1. Tension of STL of Kursk region, rather “east” STL, according to table 1, are insignificant and allow to unite the considered STL in the uniform cluster corresponding to 1 level of tension.
2. Level of tension of STL “central” is on average 70% higher, than at the others. It is connected with big levels: urbanization, application of computer facilities, education and providing with medical services.
3. The greatest deviation on levels of tension is observed between STL “central” – “Soutwest”, “central” – “Norwest” and “east” – “central”, but does not exceed level “optimum tension. It confirms features of the second conclusion.
4. The smallest distinction is observed in couple of “Soutwest” – “Norwest”, allowing to unite data of STL in one cluster and, therefore, to apply to management of them similar decisions.
5. The matrix presented in table 3 is not symmetric. This fact says that in the analysis of trains of informative indicator signs for adoption of the most adequate administrative or correcting decision on the principle of situational analogies it is necessary to consider differences between calculations when

using calculation of relative sizes. In case of obvious not the symmetry is recommended to use additional information on results of calculations in other couples (or other combinations) the considered STL.

### 3. Conclusion

The offered method of coding of STL based on ranging of feature space on degree of the informational content estimated by experts allows to classify STL by calculation of a special code taking into account calculation of values of function of accessory to each sign which argument is the natural logarithm from a relative deviation of size of indicator sign from a certain nominal rate. The STL total indicator decimal code allows not only to classify a landscape by the level of tension, calculated as a binary logarithm of function which argument is the relative deviation of a decimal code strictly certain (or calculated according to the set criterion) a train of indicator signs, but also to unambiguously restore a train that allows to analyze and describe differences in, sociotechnical landscapes. Application of the offered coding type together with methods of decrease in dimension of feature space (main a component, hierarchies, the factorial analysis, etc.) allows to display multidimensional feature space in one, two and three-dimensional spaces, to carry out in it a clustering of objects and “to come back” to initial space without information losses.

Thus, the received results of practical researches STL of Kursk region of the Russian Federation allow to draw a conclusion on prospects of application of the considered applied method of the mathematical analysis and classification of, sociotechnical landscapes in the information and analytical systems of expert type.

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