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Socio-Economic Nonlinear Dynamics Processes for Forecast and Pre-Forecast Information Based on Time Series

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Phase portrait; Dimensional rectangle; Phase analysis; Quasicycle; R/S analysis; Hurst exponent; Tourist flows.

Abstract

The paper presents a system of models and methods of nonlinear dynamics to study socio-economic processes and obtain pre-forecast and forecast information based on time series. The developed software toolkit Methods of nonlinear dynamics system (MNDS) implements the following functionality: calculation of statistical indicators with the construction of an empirical distribution function; phase analysis, R/S analysis. A distinctive feature of the complex is working with both short time series and large data. The presented analysis and forecast tool is aimed at studying aspects of the cyclical nature of socio-economic processes using the example of information about tourist flows and opportunities for an analyst, without delving into rather complex calculations and using the data obtained, to develop management recommendations for further decision-making and, accordingly, the implementation of practical action.

Disciplinary: Information Systems, Application, and Analysis, Mathematics.

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1 Introduction

Modern economics requires creating mathematical modeling tools using the foundations of artificial intelligence, including the development and development of new methods, in particular, such as phase analysis, the Hurst normalized range method, and other nonlinear dynamics methods [1, 2, 3].

The analysis and forecast tool presented in this work aims to study aspects of the cyclical nature of socio-economic processes using information about tourist flows and opportunities for an analyst. Without delving into rather complex calculations and use the data obtained to develop management recommendations for further decision-making and, respectively, the implementation of practical actions [8, 10].

The paper presents the developed tool "Methods of nonlinear dynamics system (MNDS)" [4] based on the Python 3.7.6 programming language using the QT Designer 5.11.2 graphical interface design environment. The following libraries are connected to Python 3: matplotlib, NumPy, sklearn, pandas, xlrd, xlwt, PyQt5.

The purpose of the article is to demonstrate the advantages of the developed software product and present a comparison of the results of pre-predictive time series (TS) analysis with their inherent cyclicity, which are obtained based on fractal and phase analysis. The listed methods relate to the pre-forecast analysis of time series [2, 8, 9].

2 Materials AND Methods

The time series of the tourist flow to the Dombai ski village of the Karachay-Cherkess Republic was used as an object of research. A study was conducted based on daily data of registered tourists for the period from 2015 to 2017. The initial TS "Tourists" has a clear seasonal cycle [5], and the decomposition of this time series by days of the week reveals several qualitative characteristics:

$$Z = \langle z_i \rangle, \quad i = 1,2,\ldots,N, \tag{1}$$

where N – the number of TS elements corresponding to the number of observations or levels that make up TS.

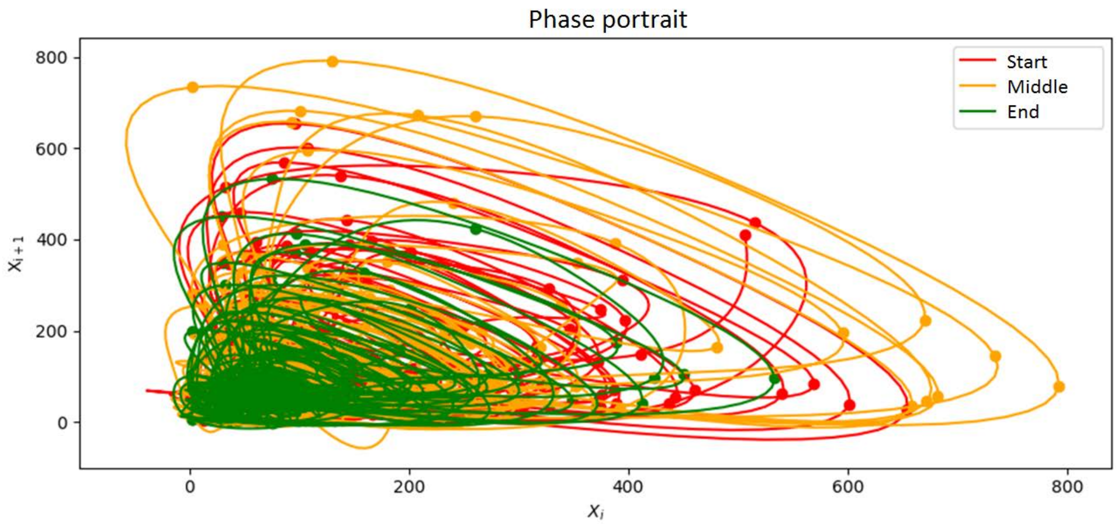


Figure 1: Phase portrait of the time series of daily tourist flows for the period 2015-2017.

In [3, 6], the construction of phase portraits of TS (1) in the phase space $F(Z)$ dimensions 2: $F(Z)=\{(z_i, z_{i+1})\}$, $i=1,2,\ldots n-1$ allows you to identify any properties inherent in socio-economic processes. Of particular interest is the study of the dynamics of the process under study, which allows us to make the three-color coloring of the time series proposed by the authors, respectively, to three equal periods: from 05/01/2015 to 03/03/2016 (red), from 03/04/2016 to 01/06/2017 (yellow) and from 07.01.2016 to 12.11.2017 (green). Figure 1 shows the phase trajectory of TS "Tourists" from 05/01/2015 to 11/12/2017 in a three-color livery.

One key point is the estimation of the phase space dimension (r). To determine it, the fractal approach was used, detailed in the source [7]. The value of the Hurst exponent calculated for the TS analyzed in this work is H = 0.63 (see Figure 2), respectively, we obtain an estimate of the dimension D = 2 - H <2 [7], and thus the value of the dimension of the phase space r =2 (R/S analysis refers to the rescaled range analysis method).

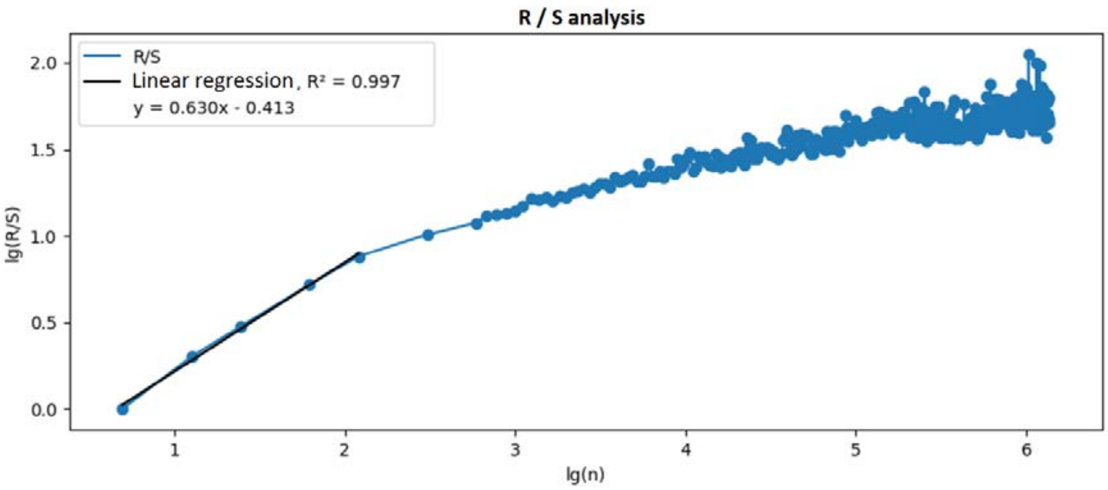


Figure 2: R/S-trajectory of TS Tourists. The value of the Hurst exponent is H = 0.63

The algorithm for studying the phase trajectory, namely, its decomposition into quasi-cycles [2], is implemented in the presented software product. The search for quasi-cycles is carried out in an automatic mode. Let us note the difference inherent in the process under study. The constructed phase trajectory consists mainly of such quasi-cycles, the length of which is 5 days, despite the seemingly natural presence of seven-day "quasi-cycles". Figure 3 demonstrates this result. The phase portrait trajectory is 159 quasi-cycles C_r, $r=1, 2, \ldots, 159$, which do not intersect with each other.

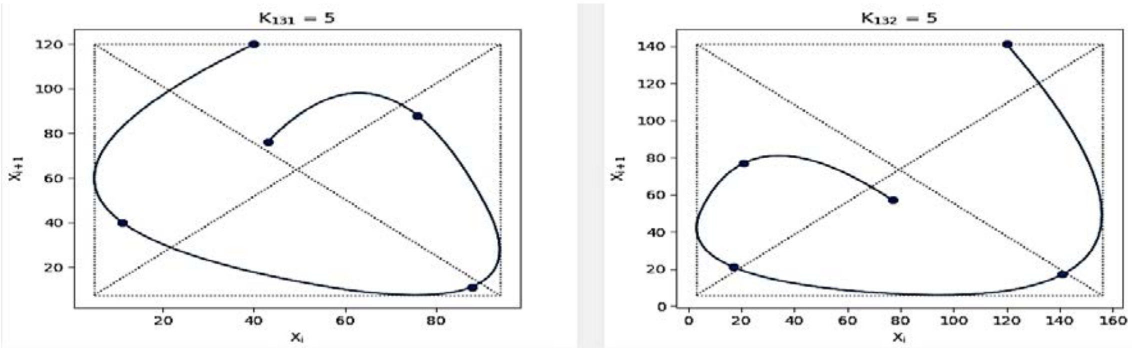


Figure 3: Quasi-cycles - results of the MNDS program.

3 Result and Discussion

The statistics of the selected quasi-cycles, presented graphically in Figure 4, allow us to conclude: long-term memory is due to the presence of a cyclic component in the process under study. The length of the quasi-cycles with the highest frequency is L = 5.

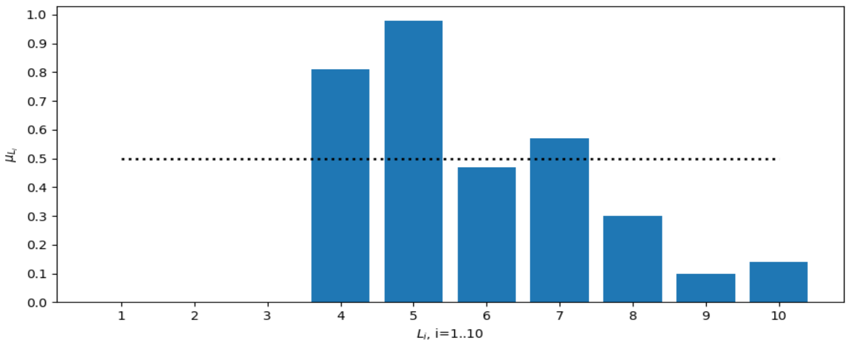


Figure 4: Graphical interpretation of the membership function of the lengths of quasi-cycles with corresponding frequencies

The next step of the study (see Figure 5), implemented in the automatic mode, is the determination and graphical presentation of the dynamics of the minimum and maximum values of the quasi-cycles of the phase portrait and the dynamics of the centers of the "dimensional rectangles of quasi-cycles" [2] of the TS under study.

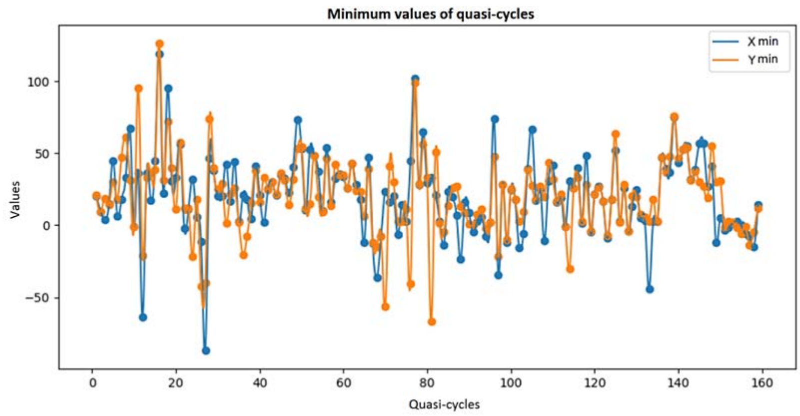


Figure 5: Illustration of the results of the work of the tab "Maxima" and "Minima" of the MNDS program.

For drift trajectory of the centers of quasi-cycles, Areas are presented respectively in Figures 6 and 11 - the evolution of the centers of quasi-cycles and the areas of dimensional rectangles and the time series under study [2]. The range of quasi-cycles of dimensional rectangles of the investigated time series was R ≈ 415.9–22.4 = 393.5 (peoples).

The analysis of the phase portraits based on an automated algorithm makes it possible to identify many characteristic features inherent in the TS under study:

- lengths of quasi-cycles lÎ [4;10], which in turn is confirmed by the results of fractal analysis (see Figure 2) [7];

- conclusion about the weak structuring of the process under study follows from the fact that in the constructed quasi-cycles there are links directed counterclockwise;

- dynamics of centers of quasi-cycles $O_r(x_r, y_r)$, $r = \overline{1, 159}$ is carried out along a trajectory, the points of which are located in a sufficiently small neighborhood of the bisector of the positive orthant of the Cartesian coordinates (see Figure 7);

- calculated coefficient of variation for the investigated TS "Tourists" is equal to 103.6% and significantly exceeds 30%, which indicates high volatility of the investigated process.

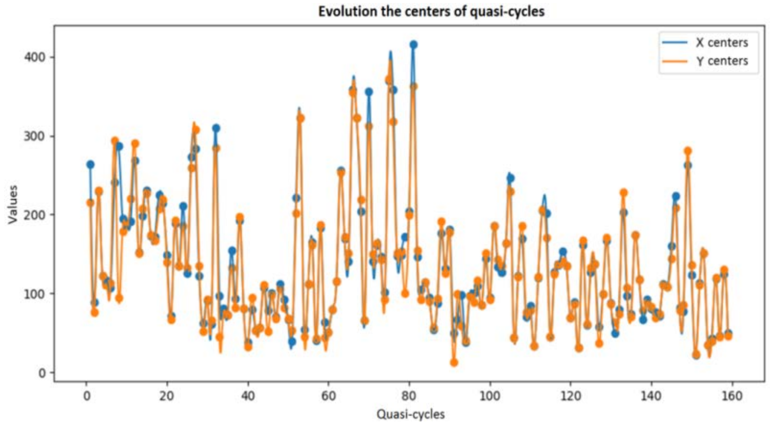
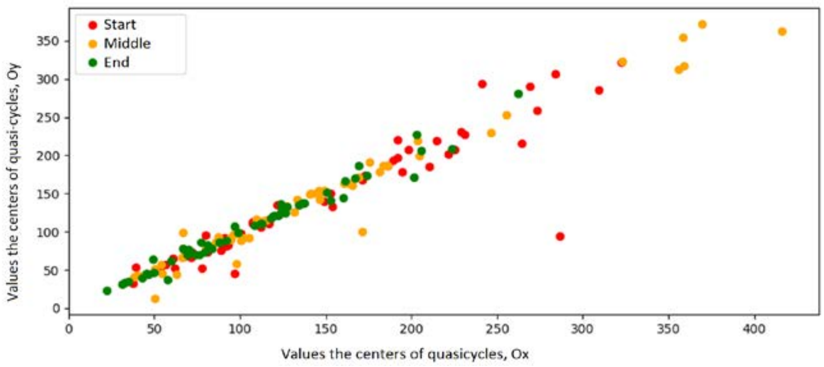


Figure 6: Evolution of the centers of quasi-cycles of dimensional rectangles of the investigated Tourists TS.

A detailed study of the dynamics of TS "Tourists" allows the program to color the values of the time series in the time intervals selected by the researcher. As can see in Figure 7, the values related to the TS Tourists' end (colored green) are grouped closer to the origin. It is of practical interest to study TS "Tourists" in more detail, dividing it into the three periods described above, separately examining each.



Y = 0.9387X + 4.7209

Figure 7: Evolution of the centers of quasi-cycles Tourists TS (Drift trajectory of centers) with the construction of the regression

Visualization of Figures 8-10 allows the following conclusions to be drawn:

- Range of the first sub-period is R1»309.45–37.85=271.6 (peoples);

- Swing of the second subperiod is R2»416.38–387.15=378.23 (peoples). The presence of high value characterizes this period from all calculated minima of the centers of the dimensional rectangles, which may indicate the formulation of the MAX/MIN problem;

- Swing of the third period is R3»262.4–22.4=240 (peoples). This period is characterized by the presence of low value from all calculated maxima of the centers of the dimensional rectangles, which may indicate the statement of the MINMAX problem;

- Minimum value of the centers of the dimensional rectangles varies in the range. It means that in the periods under consideration there is no such week during which at least 22 peoples will call in (that is, equal to the number of passengers of one sightseeing bus);

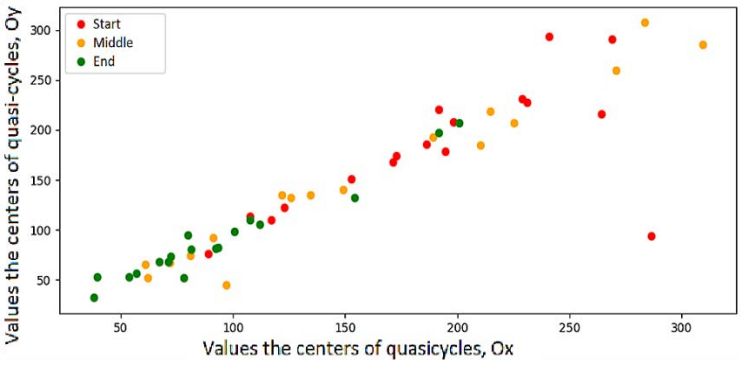
- maximum value of the centers of the dimensional rectangles varies in the range. It means that you will not have to expect an influx of tourists on average, more than 378 people (about 12-13 sightseeing buses);

- scope of the data for the third period, referring to the period of the 2017 crisis, is the smallest;

- range of data for the second period related to 2016 is the maximum;

- regression equations of the constructed drift trajectories of the centers of the dimensional rectangles are practically equal to the bisector y » x (Figures 8b, 9b, 10b);

- evolution of the dimensions (area) of the dimensional rectangles of quasi-cycles is cyclical, which follows from the visualization of Figure 8.



$$Y = 0.92 \times x + 6$$

Figure 8: Trajectory of movement of the centers of dimensional rectangles of the first period of the Tourists time series.

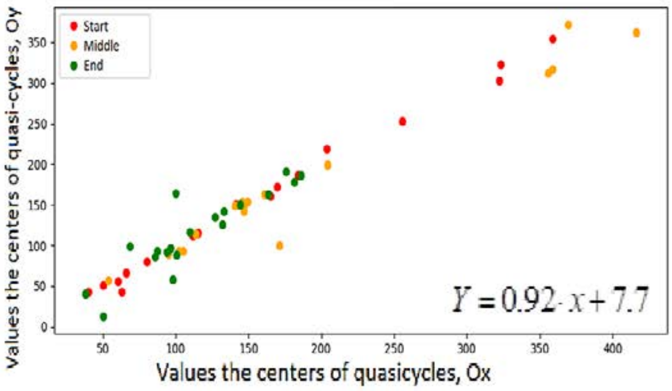


Figure 9: Trajectory of movement of the centers of the dimensional rectangles of the second period of the Tourists time series

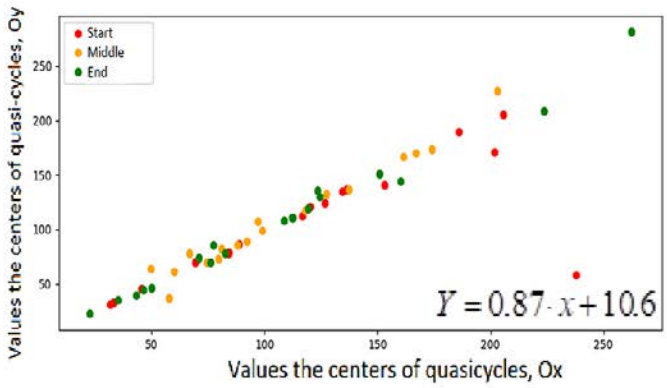


Figure 10: Trajectory of movement of the centers of the dimensional rectangles of the third period of the Tourists time series.

The summary results of the study of the Tourists time series by periods by the methods of phase analysis and R / S-analysis [3, 8] are in Table 1.

Table 1: Forecast characteristics of the Tourists time series by periods

Indicators of pre-predictive analysis \ TS name		Tourists TS		
		I period	II period	II period
Phase Analysis	Length of quasi-cycles with the highest frequency	5	4	5
	The corresponding frequency of the length of quasi-cycles	15	16	19
	Regression equation of the trajectory of movement of the centers of the dimensional rectangles	$Y = 0.92 \times x + 6$	$Y = 0.92 \times x + 7.7$	$Y = 0.87 \times x + 10.6$
R/S analysis	Hurst exponent value	0.64	0.63	0.6
	Regression equation	$Y = 0.64 \times x - 0.42$	$Y = 0.63 \times x - 0.41$	$Y = 0.6 \times x - 0.38$
	R/S trajectory stall point	6	6	6

Analysis of the calculated data in Table 1 allows us to draw the following conclusions:

- lengths of the quasi-cycles with the highest frequency are 4 and 5, respectively, which is the number of weekdays;

- one of the pre-predictive characteristics is the highest frequency of the length of quasi-cycles, which characterizes the "const" property of the process under study. The third period TS Tourists has the highest value of this indicator, which means the presence of frequently encountered 5-day quasi-cycles;

- regression equation for trajectories of centers overall rectangles is the same for all studied TSs, this conclusion allows us to analyze the coefficient a, the value of which ranges from 0.87 to 0.92;

- for each of the studied time series, the sixth point of breakdown from the R/S-trajectory is fixed On average, the duration of 6 days characterizes weekdays (week), which provides pre-forecast information for determining the memory depth of the time series;

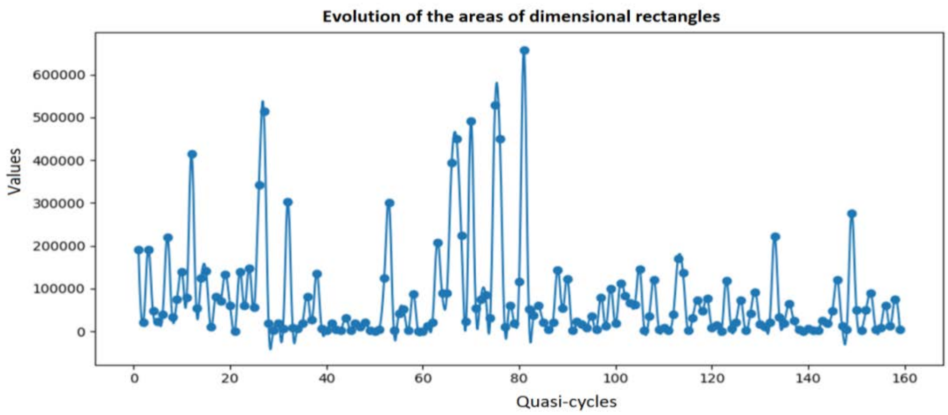


Figure 11: Graphical interpretation of the dynamics of the areas of the dimensional rectangles of the original Tourists time series.

For all the time series, the Hurst exponent's value belongs to the zone of "gray" noise. The latter means that the data series do not follow random walks [1]. A decrease in the value of the Hurst exponent by periods TS "Tourists" means an increase in the volatility of the process under study;

- regression equations are of the same type for all studied TS, this conclusion allows us to analyze the coefficient a, the value of which ranges 0.60-0.64.

The listed results, obtained in a detailed study of the dynamics of the time series of the tourist flow, allow us to conclude the complex stochastic nature of the process under study. The swing value first increases, and then in the third period takes on a value lower than the previous periods.

Presented in the article approbation of the developed tool for TS "Tourists" allows us to offer for socio-economic TS of this type, having fractal properties, a multi-stage approach to predicting their dynamics.

Stage 1. Computing in a fuzzy format the set of the TS memory depth estimate.

Stage 2. Determination of the fractal dimension of the phase space of the studied TS.

Stage 3. Revealing the presence of quasi-cycles in phase portrait, and determining both initial and final quasi-cycle even in the case of their incompleteness.

Stage 4. Determination of the direction of rotation of the links of quasi-cycles, identifying the dynamics of the centers of quasi-cycles and the areas of dimensional rectangles in which these quasi-cycles are embedded.

Stage 5. Integrated use of the obtained analytical information for a forecast based on the principle of continuation (completion) of the corresponding quasi-cycle, taking into account the peculiarities, namely, whether the quasi-cycle to which the forecast point belongs is completed or incomplete [11, 12].

4 Conclusion

The predictive approach stands out as a new implementation of accounting for trends (the trajectory of the drift of the centers of the dimensional rectangles), makes it possible to sequentially select quasi-cycles, to plot the movement of areas and centers of the dimensional rectangles. In the realities of the present, the authors have to expand and adapt the functionality of the developed complex of models and methods for studying the influence of event components, both planned (for example, competitions starting from the local level and ending with the global one) and not planned (for example, the Covid-19 pandemic in 2020) on the dynamics of socio-economic systems and assessment of their consequences.

5 Availability of Data and Material

Data can be made available by contacting the corresponding authors.

6 Acknowledgment

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