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APPROACH TO GAS CONSUMPTION PROCESS FORECASTING ON THE BASIS OF A MATHEMATICAL MODEL IN THE FORM OF A RANDOM CYCLIC PROCESS

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Abstract: In the article, the approach to gas consumption process prediction on the basis of a mathematical model in the form of a cyclic random process is considered. The prediction is based on statistical information for previous years of gas consumption. An additive combination of three components was used as a mathematical model of gas consumption process: a cyclic random process, a trend component and a stochastic residue. The first component of the mathematical model in the form of a cyclic random process takes into account the scale factors, information about which is considered at the stage of prediction. Based on the caterpillar decomposition, ten components of the singular decomposition are obtained. The sum of nine components of singular decomposition forms a cyclic component – a cyclic random process. This component takes into account the scale factors of the amplitude of gas consumption process in each segment-cycle. The trend component of the mathematical model is the second component of the singular decomposition, and the stochastic residue is formed on the basis of the difference between the values of the studied gas consumption process and the sum of the cyclic and trend components. Computer simulation of realization of cyclic component of gas consumption process is carried out in the work, and also the annual forecast of gas consumption is made. The prediction results are compared with the real gas consumption process (information for last year's gas consumption was used). This paper does not take into account the effects of climatic conditions on the gas consumption process, but this is going to be done in further research, which will improve the accuracy of computer simulation and prediction.

Keywords: *cyclic process, gas consumption process, statistical processing, segmentation, cyclic random process*

Introduction (statement of the problem)

Gas consumption management is of particular urgency nowadays. The ability of analysis, simulation and prediction of gas consumption process are the vital problems set by the world leading gas companies. For their effective solution, modern software and hardware systems are needed that will provide the possibility to develop and control the gas consumption process. Development of new software complexes demands the improving of mathematical software, which involves the development of new mathematical models and methods of gas consumption processing. This will ultimately allow to form the forecast results based on the information obtained.

Objectives of the research

This research deals with creating a new mathematical model of gas consumption process using stochastic approach in the form of additive combination of three components, one of which is a cyclic random process that takes into account scale factors, other components are trend and stochastic residue.

Analysis of recent research

Consider the known approaches to forecasting gas consumption and analysis of their models. In [1, 2] the method of short-term forecast is described, which makes it possible to analyse and calculate the predicted values of gas consumption in the heating season, taking into account its cyclicity and ambient temperature. There are also approaches to forecasting natural gas consumption using a system of fuzzy conclusions based on the adaptive network (ANFIS) [3]. The combined method of forecasting natural gas consumption using the Bayesian model averaging (BMA) is given in [4]. The research [5] proposes an approach such as "grey forecast with a moving mechanism" (GPRM). In [6], a method for predicting natural gas consumption using neural networks and methods of multidimensional time series is described. In [7], a model for forecasting daily gas consumption is presented, designed for forecasting in a short range for 1-5 days in advance. The forecast of natural gas demand based on the combinational forecasting model is given in [8]. The study [9] described a method for predicting the need for gas using artificial neural networks, design and training was performed using MLP (multilayer perceptron model). The variety of approaches to forecasting suggests that the tasks of forecasting need to be developed and improved, which applies to both short- and long-term forecasting.

The main part

Mathematical model of the random cyclic gas consumption process $\xi'(\omega,t)$ is presented as an additive model (1) which consists of three components.

$$\xi'(\omega,t) = \xi(\omega,t) + f_{tr}(t) + f_{rem}(\omega'',t), t \in \mathbf{W}, \omega \in \mathbf{\Omega}, \omega'' \in \mathbf{\Omega}'' , \qquad (1)$$

where $\xi(\omega,t)$ is a cyclic component, $f_{tr}(t)$ is a trend function, $f_{rem}(\omega'',t)$ is a stochastic residue function.

In practice we are dealing with discrete data, we present mathematical model (1) is as follows

$$\xi'_{\omega}(l) = \xi_{\omega}(l) + f_{tr}(l) + f_{rem\omega''}(l), l \in \mathbf{W} = \mathbf{D} , \qquad (2)$$

where $\xi_{\omega}(l)$ is implementation of cyclic component of gas consumption process, $f_{tr}(l)$ is a trend function, $f_{rem\omega''}(l)$ is a function of stochastic residue, l stands for discrete samples of gas consumption process, L is a number of samples of gas consumption process (registered implementations).

For obtaining the components of mathematical model (2) during processing of the real cyclic gas consumption process $\xi'_{\omega}(l), l = \overline{1,L}$ we apply the SSA-caterpillar method. This method is given in [10] and describes the transformation of a one-dimensional time series into a multidimensional one, which makes it possible to obtain components of a singular segmentation.

When applying the caterpillar method, we obtain k implementations of components $\left\{\bar{f}_k(l), k = \overline{0, K-1}, l = \overline{1,L}\right\}$, where $K = 10$, l stands for parts of gas consumption process during 2006-2019, L is the number of discrete implementation samples.

The cyclic component is obtained by summing the components obtained on the basis of the caterpillar method, in particular, components: 0-1,3-9, component 2 is a component of the trend $\bar{f}_2(l)$

$$\xi_{\omega}(l) = \sum_{k=0}^{1} \bar{f}_k(l) + \sum_{k=3}^{9} \bar{f}_k(l), l = \overline{1,L}, \qquad (3)$$

$$f_{tr}(l) = \bar{f}_2(l), \ l = \overline{1,L}. \qquad (4)$$

The stochastic residue is obtained on the basis of the relation:

$$f_{rem\omega''}(l) = \xi'_{\omega}(l) - (\xi_{\omega}(l) + f_{tr}(l)), \ l = \overline{1,L}, \qquad (5)$$

Consider $\xi_{\omega}(l)$, the cyclic component of the mathematical model (1), which carries information about the process of gas consumption in more detail, we present it as

$$\xi_{\omega}(l) = \sum_{i=1}^{C} f_i(l), l \in \mathbf{W}, \qquad (6)$$

where C is the number of segments-cycles of the cyclic process of gas consumption, $\mathbf{W}$ is the domain of determining the cyclic process of gas consumption, and the domain of its values, for the case of the stochastic approach is the Hilbert space of random variables given on one probabilistic space $\left(\xi_{\omega}(l) \in \mathbf{\Psi} = \mathbf{L}_2(\mathbf{\Omega}, \mathbf{P})\right)$. In the design (6), the segments-cycles $f_i(l)$ of the cyclic gas consumption process are determined by indicator functions, i.e.

$$f_i(l) = \xi_{\omega}(l) \cdot I_{\mathbf{W}_i}(l), i = \overline{1,C}, \ l \in \mathbf{W}, \qquad (7)$$

Herewith, the indicator functions, which allocate segments-cycles, were defined as:

$$I_{\mathbf{W}_i}(l)=\begin{cases}1, l\in \mathbf{W}_i,\\ 0, l\notin \mathbf{W}_i.\end{cases},\ i=\overline{1,C}, \qquad (8)$$

where $\mathbf{W}_i$ is the domain of determining the indicator function, which in the case of a discrete signal, i.e. $\mathbf{W}=\mathbf{D}$, is equal to a discrete set of samples

$$\mathbf{W}_i=\left\{l_{i,j},\ j=\overline{1,J}\right\},\ i=\overline{1,C}, \qquad (9)$$

The segmental cyclic structure $\hat{\mathbf{D}}_c$ is taken into account by the set of time samples $\{l_i\}$ or $\left\{l_{i,j}\right\}, i=\overline{1,C}$, $j=\overline{1,J}$, where J - is the number of discrete samples in the cycle. This notation of the mathematical model (9) takes into account the rhythm of the cyclic gas consumption process due to the continuous function of the rhythm $T(l,n)$ namely

$$I_{\mathbf{W}_i}(l)=I_{\mathbf{W}_{i+n}}(l+T(l,n)),\ i=\overline{1,C},\ n=1,\ l\in\mathbf{W}, \qquad (10)$$

In order to estimate the rhythm function $T(l,n)$, the segment structure of gas consumption process (in this case the segment cyclic structure) was first determined as $\hat{\mathbf{D}}_c=\{l_i, i=\overline{1,C}\}$ which is a set of time moments that correspond to the boundaries of the segments-cycles of gas consumption process. In this case, the estimation of the segmental cyclic structure of gas consumption process can be performed using the segmentation method presented in [11]. It has been shown before that segmentation of gas consumption process is better not to carry out on the vertices, but on the depressions, which does not allow "blurring" of statistical estimates after processing the studied implementation.

The example of computer simulation of gas consumption process based on the mathematical model (1) is presented in Figure 8.

To adequately describe the real gas consumption process, it is also necessary to consider changes in the load amplitude on the segments-cycles, which are caused by various factors, such as climate (temperature, pressure, wind force etc.). In the design of mathematical model (1), the cyclic component (6) takes into account the segments-cycles of cyclic gas consumption process as multiplicative components considering the indicator functions and scale factors of gas consumption amplitude, i.e.

$$f_i(l)=\xi_\omega(l)\cdot\alpha_{\mathbf{W}_i}(l)\cdot I_{\mathbf{W}_i}(l),\ i=\overline{1,C},\ \ l\in\mathbf{W}, \qquad (11)$$

In formula (11), an additional component $\alpha_{\mathbf{W}_i}(l)$ that reflects the scale factors of gas consumption amplitude in each segment-cycle of the cyclic process, are introduced

$$\alpha_{\mathbf{W}_i}(l)=\begin{cases}\alpha_i, l\in \mathbf{W}_i,\\ 0, l\notin \mathbf{W}_i.\end{cases},\ i=\overline{1,C}, \qquad (12)$$

where α_i stands for the scale factors of gas consumption amplitude at every i-segment-cycle, are determined as follows:

$$\alpha_i=\frac{\alpha_{i\max}}{\alpha_{aver}},\ i=\overline{1,C}, \qquad (13)$$

where $\alpha_{i\max}$ is the maximum value of gas consumption range at i-segment-cycle (determined at the stage of segmentation of cyclic gas consumption process), α_{aver} is the average value of gas consumption range (the maximum value of estimation range of mathematical expectation, is determined at the stage of statistical processing of cyclic gas consumption). The block diagram of the new approach to gas consumption process simulation will look as in Figure 1.

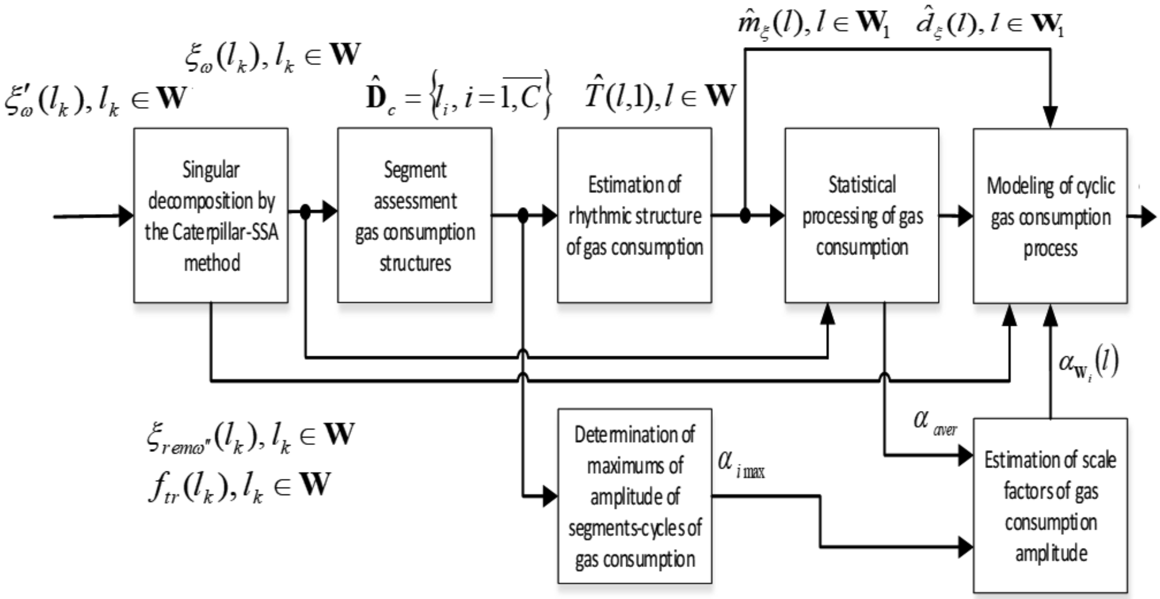


Figure 1. Block diagram of the method of computer simulation of gas consumption process

Consider and compare the results of computer simulation of gas consumption process, taking into account the scale factors of the component (11) and the component (7) of mathematical model.

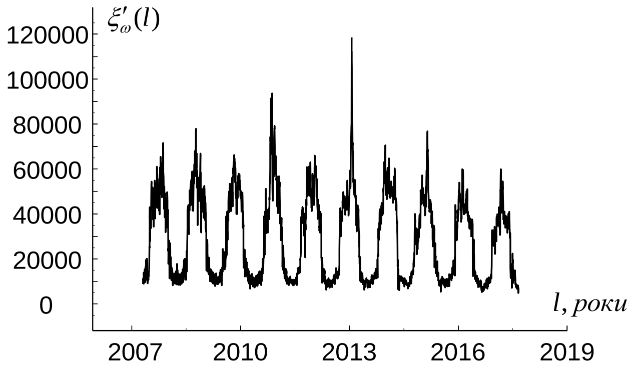


Fig. 2: Fragment of input implementation of cyclic gas consumption process

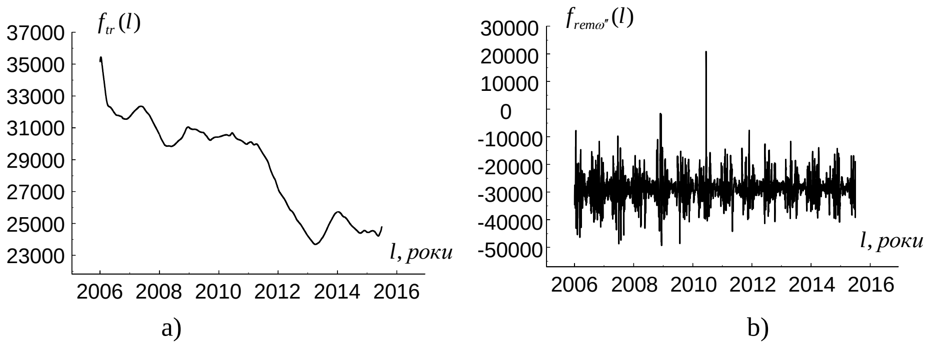
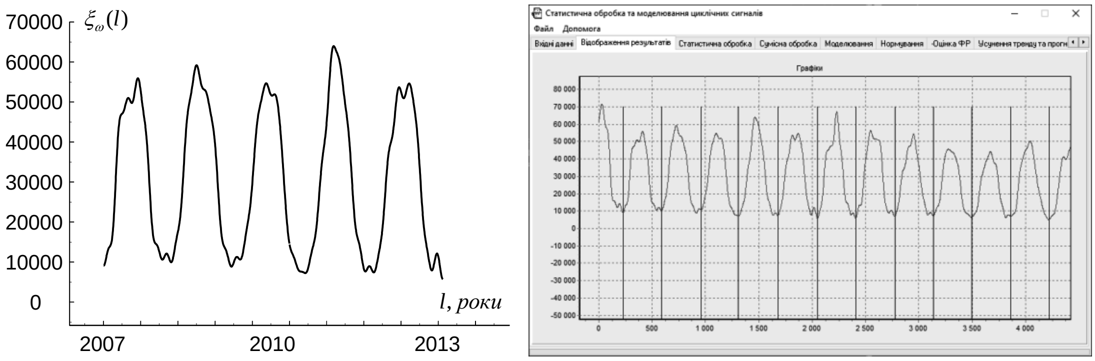


Fig. 3: Estimated components of the mathematical model: a) trend component; b) stochastic residue



a) b)

Fig. 4: Fragments of the studied implementation of gas consumption process for the case of segmentation by depressions: a) cyclic component; b) results of segmentation of the cyclic component into segments-cycles (on the abscissa axis the data are given in conventional units, the specified number of samples)

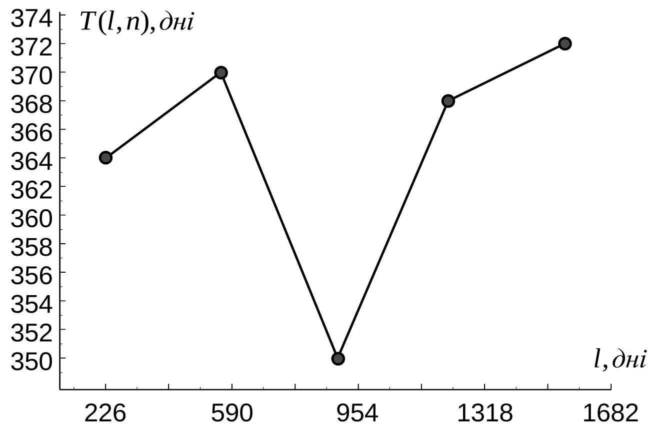


Fig. 5: Fragments of the result of estimated rhythm function (piecewise linear interpolation) of cyclic component of gas consumption process (based on segmentation into cycles by depressions)

Having obtained the segment structure $\hat{\mathbf{D}}_c$ and estimating the rhythmic structure (discrete rhythm function $T(l,n)$) by the methods proposed in [12, 13], the methods of statistical processing were applied taking into account the rhythm function [12, 13], while the estimation of mathematical expectation was determined:

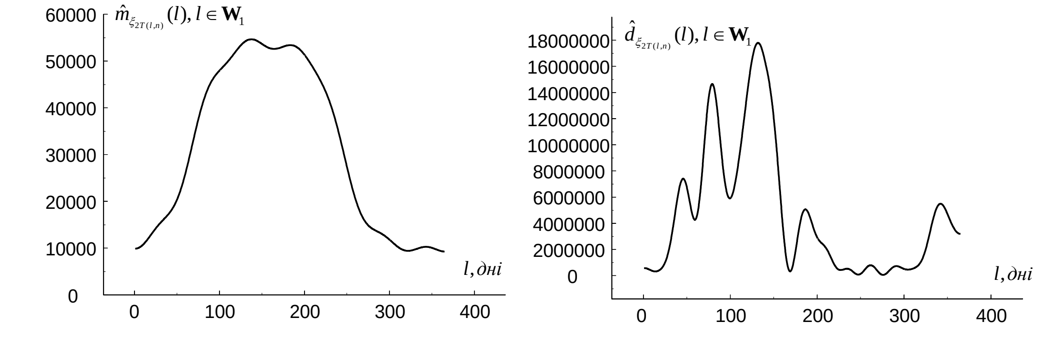
$$\hat{m}_{\xi_{T(l,n)}}(l) = \frac{1}{M}\sum_{n=1}^{M}\xi_\omega(l+T(l,n)),\ l \in \mathbf{W}_1 = [l_1, l_2), \tag{14}$$

where $l_1 \neq 0$ in the general case, l_1, l_2 are discrete time samples which correspond to the beginning and end of the first segment-cycle, M is the number of cycles.

And the estimation of variance was determined as follows:

$$\hat{d}_{\xi_{T(l,n)}}(l) = \frac{1}{M}\cdot\sum_{n=1}^{M}\left[\xi_\omega(l+T(l,n)) - \hat{m}_{\xi_{T(l,n)}}(l+T(l,n))\right]^2,\ l \in \mathbf{W}_1 = [l_1, l_2), \tag{15}$$

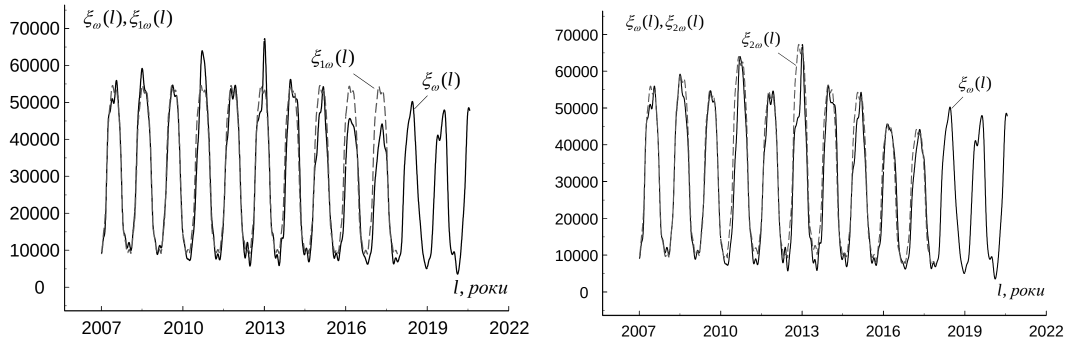
Applying the methods of statistical processing, we obtained statistical estimates of probabilistic characteristics (mathematical expectation $\hat{m}_{\xi_{T(l,n)}}(l),\ l \in \mathbf{W}_1$ and variance $\hat{d}_{\xi_{T(l,n)}}(l),\ l \in \mathbf{W}_1$ based on the rhythm function $T(l,n)$ of the cyclic component of gas consumption process. Examples of the obtained estimates are given in Figure 7.



а) б)

Fig. 7: Estimation of mathematical expectation and variance based on the estimated rhythm function of cyclic component of gas consumption process (segmentation into cycles by depressions): a) estimation of mathematical expectation; b) estimation of variance

Taking into account the obtained statistical estimates, carry out the computer simulation of cyclic components of gas consumption process implementations on the basis of two mathematical models (7) and (11).



a) b)

Fig. 8: Results of computer simulation of the cyclic component of gas consumption process based on two mathematical models: a) implementation of the cyclic component of gas consumption process of real data and simulated on the basis of a known model (7); b) implementation of the cyclic component of gas consumption process of real data and simulated on the basis of a new model (11)

In order to describe the approach to forecasting the gas consumption process, we determine the scale factor of gas consumption range for the forecast cycle (for example, in 2013) based on the average arithmetic value of gas consumption maximums range for 2007-2012. Note that this approach does not take into account information about climatic factors that affect the gas consumption process (temperature, pressure, humidity, etc.) for 2007-2012, as well as projected (expected) values of climatic indicators for 2013. However, the morphology of the gas consumption cycle segment $f_6(l)$ is taken into account on the basis of statistical information for previous years 2007-2012 in the form of an estimate of mathematical expectation (see Fig. 7, a).

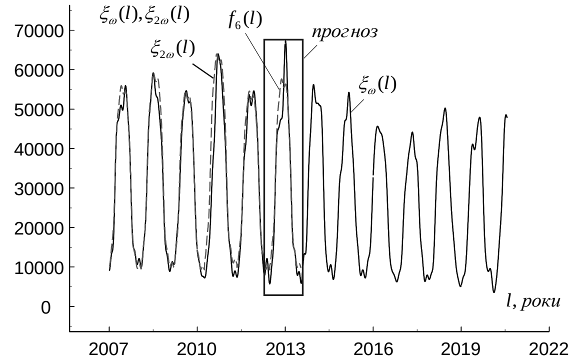


Fig. 9. Results of computer simulation of cyclic component of gas consumption process (2007-2012) and forecast of the gas consumption process for 2013

Figure 9 presents the forecast of annual gas consumption without taking into account climatic factors based on last year's gas consumption data. The dotted line shows the simulated values of gas consumption based on scale factors.

As climatic factors that significantly affect the consumption of natural gas by the population are not taken into account, the value of the maximum forecast amplitude is not defined precisely enough. In further scientific research there are going to be taken into account both climatic factors for previous years and forecasted (expected) climatic factors when drawing the annual gas consumption forecast.

Conclusions

In the research, an approach to forecasting the gas consumption process based on a mathematical model in the form of an additive mixture of three components: a cyclic random process taking into account scale factors, trend component and stochastic residue is developed. A new way to population gas consumption forecasting the is proposed, does not take into account climatic factors that significantly affect the process of gas consumption. The application of the proposed model considering the scale factors allowed to increase the accuracy of computer simulation (for 2007-2012), as evidenced by the obtained results.

In further research the values of scale factors obtained on the basis of aggregated data of climatic indicators in the developed mathematical model will be taken into account and comparative analysis of computer simulation of gas consumption based on a new mathematical model is going to be conducted.

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