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Computer Aided System of Time Series Analysis Methods for Forecasting the Epidemics Outbreaks

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***Abstract*— The research is devoted to the problem of predicting the incidence of gastroenterocollitis. The paper discusses the forecasting of time series by statistical models. The methods of exponential smoothing and adaptive exponential smoothing are proposed, applied to additive and multiplicative time series models. The analysis of the results obtained using the developed computer aided system.**

Keywords—forecasting of time series, forecasting the epidemic process, method of exponential smoothing, Brown polynomial model, adaptive Holt method

I. Introduction

Epidemiological surveillance of infectious diseases and the prevention of outbreaks of certain infectious diseases is an important task of ensuring safety in the field of public health, because the occurrence of outbreaks of infection and the worsening of the epidemic situation create problems for national health services, increase financial costs, etc [1]. If you do not prevent the occurrence of outbreaks and the worsening of the epidemic situation, infections can quickly spread to other territories, causing significant medical, social and economic damage. Among current infections of modern times, foodborne diseases play a significant role, the incidence of which tends to increase in both developed and developing countries, this problem is rapidly becoming a global one. Public health is faced with the task of reducing the impact of these infectious diseases on the health and socio-economic well-being of people.

This problem requires solving the task of processing and analyzing information obtained in the course of the activity of the sanitary-epidemiological service. This is a time-consuming task that modern information technologies can facilitate.

This research is based on official data on gastroenterocolitis (GEC) cases monthly reported in Kharkiv Oblast (East Ukraine) during 2013-2017 without detection of etiological agent of infection.

GES is a total lesion of the human gastrointestinal tract (small and large intestine, as well as the stomach). Acute gastroenterocolitis, as a rule, caused by infectious agent, develops as a result of food toxicoinfections that occur when pathogenic microorganisms (bacteria, viruses, protozoa) and / or their toxins enter the body with food or water; symptoms of intoxication, vomiting, diarrhea. In the scientific literature can be found the terms "Gastroenteritis" (if the process does not involve the large intestine), "infectious diarrhoea", "acute intestinal infections", "acute diarrhoeal infection". Using data without decoding the type of pathogen that caused gastroenterocolitis, according to the preliminary diagnosis, without waiting for the results of laboratory tests, it is possible to determine in time the onset of complications of the epidemic situation and to take adequate restraining measures in time. [2]

To solve the problem, we consider it as a forecasting problem based on time series. In work [3] the factors are described, to which influence a time series is subject and four components are allocated:

- a trend that represents a non-periodic change in the average over the time interval on which the time series is determined;
- seasonal factor that determines the actions that are repeated in units of days, weeks, months, years;
- cyclical factors affecting the series;
- random factor.

In paper [4], time series models are considered: additive and multiplicative, which represent the dependence of factors. Knowing the essence of the phenomenon or process described by the time series, it will not be difficult to choose the appropriate model.

To predict epidemic processes, there are many complex methods that are characterized by the possibility of taking into account a large number of factors affecting the dynamics of the incidence of diseases, heterogeneity of the population and territories, and so on. Among such methods one can single out methods based on neural networks [5, 6] and multi-agent simulation [7, 8].

However, given the nature of the data that is collected on the incidence of GEC in Ukraine, we consider statistical time-based adaptive statistical forecasting methods, such as the exponential smoothing method, Holt method and Brown method. The considered methods have a number of properties [9]:

- Applicability for a wide range of tasks.

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- Forecasting is based on intensive analysis of information contained in individual time series.
- It does not require a large amount of information.
- Clarity and simplicity of the mathematical formulation.

II. Methods

The first task of investigation of the time series is to test the hypothesis of a trend. With the help of the Foster-Stewart method [10] the presence of a trend of GEC morbidity was established, a non-random component was identified. Visual analysis showed that, as a non-random component in the analyzed time series, it makes sense to distinguish between the trend and the seasonal component. To simulate the trend of time series, the moving average method was used [11]:

$$1/5\ (U_{n-2} + U_{n-1} + U_n + U_{n+1} + U_{n+2}) = 1/5\ U_n; \qquad (1)$$

where U_n is operator, which characterize the process of summing of five terms of the series.

In the modeling of seasonal variations, the values of the seasonal component were calculated.

To implement the forecast of GEC morbidity, three methods were used: the method of exponential smoothing, the Brown polynomial model, and the adaptive Holt method.

A. Method of exponential smoothing

The peculiarity of the method of exponential smoothing is that in the procedure for equalizing each observation only the values of the previous levels of a series of dynamics taken with a certain weight are used [12]. This method is recommended for short-term forecasting, for stationary data, or when there is a slow growth in data or, conversely, a decrease in time.

The exponential smoothing of the series is carried out by the recurrence formula:

$$F_t = \alpha X_t + \beta F_{t-1},\ F_0 = \frac{\sum_{i=1}^{m} x_i}{m}, \qquad (2)$$

where F_t is value of exponential average at time moment t; X_t is an element of time series, $X = \{x_1, x_2, \ldots\}$; α is smoothing parameter, $0 < \alpha < 1$; $\beta = 1 - \alpha$.

The constant α affects the accuracy of the forecast. It should also provide a minimum of forecast error. If the data has significant fluctuations or randomness, a small value should be used for α. On the other hand, data with little randomness or a clear model should use a larger value for α.

B. Brown polynomial model

The difference between a single exponential smoothing and a Brown polynomial model is the presence of additional formulas for estimating the trend, so they can be used to predict non-stationary time series [13].

The following formulas are used in a second-order adaptive polynomial model:

$$S_t' = \alpha X_t + (1 - \alpha) S_{t-1}';$$

$$S_t'' = \alpha S_t' + (1 - \alpha) S_{t-1}''; \qquad (3)$$

$$S_t''' = \alpha S_t'' + (1 - \alpha) S_{t-1}''',$$

where S_t', S_t'', S_t''' are exponential average of first, second and third order.

Initial conditions:

$$S_0' = \alpha_t - \beta b_t/\alpha + \beta c_t(2 - \alpha)/2\alpha^2;$$

$$S_0'' = \alpha_t - 2\beta b_t/\alpha + \beta c_t(3 - 2\alpha)/\alpha^2; \qquad (4)$$

$$S_0''' = \alpha_t - 3\beta b_t/\alpha + 3\beta c_t(4 - 3\alpha)/2\alpha^2.$$

Coefficients estimation:

$$b_t = \alpha / 2\beta^2[(6 - 5\alpha)S_t' - (10 - 8\alpha)S_t'' + (4 - 3\alpha)S_t''';$$

$$a_t = 3S_t' - 3S_t'' + S_{t-1}'''; \qquad (5)$$

$$c_t = \alpha / \beta^2[S_t' - 2S_t'' + S_{t-1}'''].$$

The forecast for m steps forward is written by a simple quadratic polynomial:

$$F_{t+m} = a_t + b_t m + c_t m^2 / 2. \qquad (6)$$

C. Adaptive Holt method

The three-parameter exponential smoothing model of Holt is similar to the Brown model [14], since it estimates the trend and uses it in forecasting. Equations are written in following form:

$$S_t = \alpha X_t + (1 - \alpha)(S_{t-1} + T_{t-1} + R_{t-1} / 2);$$

$$T_t = \beta dS_t + (1 - \beta)T_{t-1}; \qquad (7)$$

$$R_t = \gamma d^2 S_t + (1 - \gamma)R_{t-1},$$

where $dS_t = S_t - S_{t-1}$, $d^2S_t = dS_t - dS_{t-1}$.

The forecasting formula can be written as:

$$F_{t+m} = S_t + T_t m + R_t m^2 / 2, \qquad (8)$$

where m is number of forecasting steps.

After a few modifications, we present a model that takes into account the trend and seasonality. Adaptive Holt method takes into account these factors and is analytically recorded as:

$$T_t = C\,(X_t' - X_{t-1}') + (1 + C)\,T_{t-1};$$

$$S_t = B\,(X_t / X_t') + (1 - B)\,S_{t-L}; \qquad (9)$$

$$X_t' = A\,(X_t / S_{t-L}) + (1 - A)\,(X_{t-1}' - T_{t-1}),$$

where T_t is trend from time factor, S_t is seasonal factor, L is period of seasonal cycle, X_t' is smoothed series.

The scheme of making a forecast for h steps in accordance with the adaptive Holt method is as follows:

$$X_n'(h) = (X_n' + hT_n)\,S_{n-L+h},\ h = 1, 2, \ldots, L; \qquad (10)$$

$$X_n'(h) = (X_n' + hT_n)\,S_{n-2L+h},\ h = L + 1, L + 2, \ldots, 2L. \qquad (11)$$

Adaptive Holt model suggests an additive trend and multiplicative factors, but can be modified to work with a multiplicative trend and an additive seasonal component.

Before forecasting results can be obtained, the accuracy of the forecast must be determined. To do this, you can use the formula for calculating the relative error of predicted values:

$$\varepsilon_t = (|x'(t) - x(t)| / x(t))\ 100\%, \qquad (12)$$

where $x'(t)$ is forecasted value, $x(t)$ is actual value ша time series.

III. Results

The described methods were tested on GEC incidence rates. The forecast was carried out for the October, November and December of 2017.

To automate the prediction of the incidence of GEC using C # programming language, a software package has been developed that allows calculating prognosis morbidity based on existing statistical data. The basic configuration of the software package includes data from 2013 to 2017 years. The data for the years include absolute morbidity by GEC.

Figure 1 shows number of cases of GEC and the process of predicting these indicators using the exponential smoothing method.

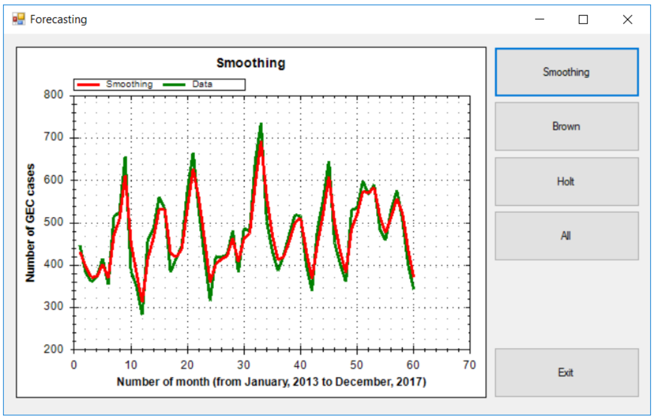

Fig. 1. Forecasting the morbidity by GEC using method of exponential smoothing

Figure 2 shows the dynamics of actual incidence rates and the process of predicting these indicators using the Brown polynomial model.

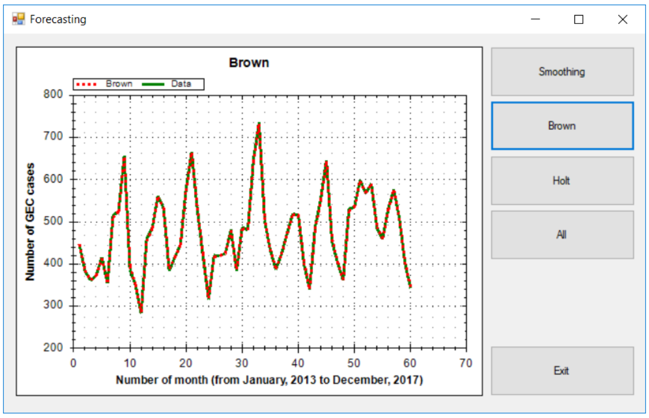

Fig. 2. Forecasting the morbidity by GEC using Brown polynomial model

Figure 3 shows number of cases of GEC and the process of predicting these indicators using the adaptive Holt method.

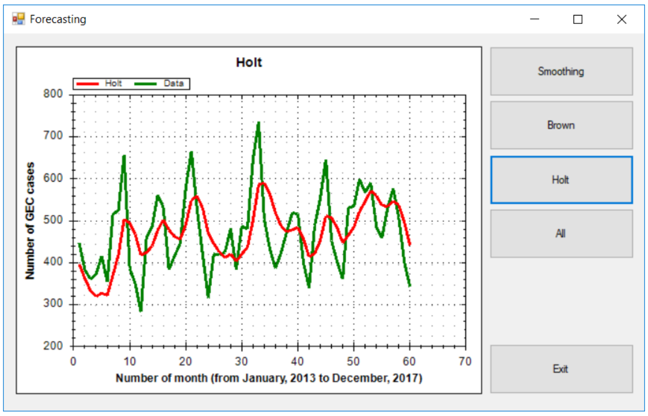

Fig. 3. Forecasting the morbidity by GEC using adaptive Holt method

A comparative analysis of the results obtained using the three methods showed that the best result is shown by the Brown polynomial model, and the worst by adaptive Holt method (fig. 4, table 1).

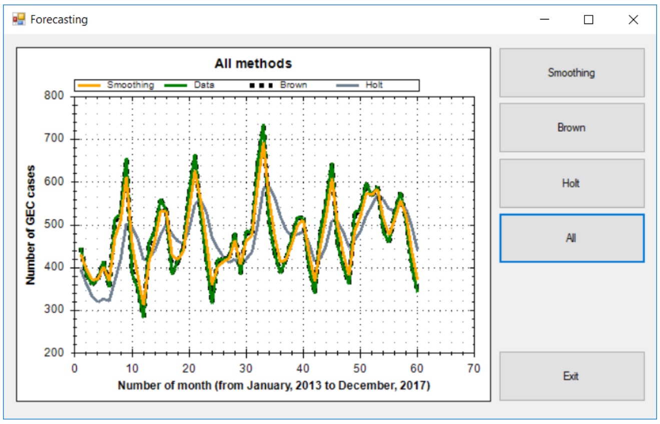

Fig. 4. Comprehensive analysis of forecasting the morbidity by GEC using method of exponential smoothing, Brown polynomial model and adaptive Holt method.

TABLE I. NUMERICAL RESULTS OF FORECASTING THE MORBIDITY BY GEC USING METHOD OF EXPONENTIAL SMOOTHING, BROWN POLYNOMIAL MODEL AND ADAPTIVE HOLT METHOD.

Number of month	**Real data**	**Forecast**		
		Exponential smoothing	***Holt method***	***Brown model***
58	508	523,012	537,86	510,18
59	401	437,604	496,514	404,53
60	343	371,381	441,572	344,99

The accuracy of the methods depends on the smoothing parameters. The prediction results showed that the accuracy of the predictions is higher with small values of smoothing constants.

Further stages of work are:

- obtaining a long-term forecast by statistical methods;
- building a forecast using neural network and fuzzy methods;
- comparison of the results obtained by neural network, fuzzy and statistical methods on real data provided by the Kharkov Regional Laboratory Center;
- implementation of a forecasting information system that allows using the web interface and calculating the forecast in real time.

IV. CONCLUSIONS

Within this study were analyzed data on the incidence rate of GEC cases in Kharkiv Oblast. Factors influencing the time series were considered: the trend, the seasonal component. The obtained results showed that the reliability of the short-term prognosis of the incidence rate of GEC cases in Kharkiv Oblast by the polynomial Brown model shows the best result. The accuracy of the methods depends on the smoothing parameters. The results of the forecast revealed that the accuracy of the forecasts is higher for small values of smoothing constants.

For further research, it is planned to implement a computer aided system as a web application in order to implement the input of data on the GEC incidence in real time, as well as the real time calculation of the predicted incidence. For this purpose it is planned to use the approaches described in paper [15]. The implementation of a computer aided system that allows calculation of the forecast in real time will increase the efficiency of decision-making on the implementation of preventive measures about decreasing GEC incidence by epidemiologists. To optimize the forecasting processes and practical use the developed model can be included in computer aided system of epidemiological surveillance of infectious diseases

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