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COVID-19 mathematical forecasting in the Russian Federation

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Abstract

A new coronavirus infection (CVI) is a challenge to the medical system of the Russian Federation and requires precise flow forecasting to take the necessary measures on time. The article provides an overview of modern mathematical tools for predicting the course of CVI in the world. The created CVI forecasting project office allowed to determine the most effective analysis tools in the Russian Federation — the ARIMA, SIRD and Holt–Winters exponential smoothing models. Implementation of these models allows for prediction of short-term morbidity, mortality and survival of patients with an accuracy of 99 % both in the Russian Federation in general and in the regions. In addition, the distribution of CVI was characterized. Particularly, Moscow and Moscow region have the maximum spread of infection, and other regions are lagging behind in the dynamics of the incidence by 1–3 weeks. The obtained models allow us to predict the course of the disease in the regions successfully and take the necessary measures in a timely manner.

Key words: prediction, forecast, COVID-19, coronavirus infection, morbidity

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Возможности математического прогнозирования коронавирусной инфекции в Российской Федерации

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Резюме

Новая коронавирусная инфекция (КВИ) является вызовом медицинской системе Российской Федерации и требует точного прогнозирования течения для своевременного принятия необходимых мер. В статье приводится обзор современных математических инструментов для проведения прогнозирования течения КВИ в мире. Созданный проектный офис по прогнозированию КВИ позволил определить наиболее эффективные в Российской Федерации инструменты анализа — модель ARIMA, SIRD и экспоненциального сглаживания Хольта–Уинтерса. С их помощью с точностью до 99 % получается прогнозировать краткосрочную заболеваемость, смертность и выживаемость пациентов как в Российской Федерации в целом, так и в отдельных регионах. Кроме того, выявлены особенности распространения КВИ. В частности, максимальная скорость распространения инфекции характерна для Москвы и Московской области, а регионы отстают по динамике заболеваемости на 1–3 недели. В статье также рассматриваются ограничения применяемых авторами прогнозных моделей. Полученные модели позволяют успешно прогнозировать течение болезни в регионах и своевременно принимать необходимые меры.

Ключевые слова: прогнозирование, COVID-19, новая коронавирусная инфекция, заболеваемость

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Existing strategies for epidemic prediction

There is a standard approach to medium-term forecasting of epidemic development, based on a generalized logistic growth model, or Richards growth model [1], sometimes sub-epidemic wave models [2] are used, based on a study of the delay in the development of an epidemic in one country from development in another country. However, the construction of short-term forecasts of high accuracy for the dissemination of confirmed cases of the disease, as well as an analysis of the number of deaths and recoveries, is also of particular interest.

The idea of short-term forecasts of COVID-19 development constructing is extremely relevant in the last 2 months. There are studies devoted to forecasting the spread of the epidemic both in countries and territories, and worldwide. With this horizon of short-term forecasting is usually 3–7 days. According to the mathematical apparatus used to build predictive models, many studies can conditionally be divided into 3 categories: classic epidemiological models of state transitions; models of the class of autoregressive moving average models (ARIMA); adaptive smoothing models.

Thus, in the People's Republic of China (PRC) epidemiological modeling tools were used in the work to short-term forecast of COVID-19 epidemic development [3]. The classical SIR model was used, which ignored the incubation period of the disease and mortality of COVID-19, and didn`t allow to ensure high quality of the obtained forecasts and to extend the forecast horizon. There are also works that use more sophisticated models: taking into account both the elimination of infections due to mortality (SIRD model in the PRC) [4] and the incubation period of the disease (SEIR model) for short-term forecasting of the epidemic in Mexico [5]. Some studies used classical epidemiological models were modified, for example, Prem K. et al. (2020) predict the development of the epidemic, the classic SEIR model was adapted to the gender and age structure of the country's population [6].

Models based on time series analysis, in particular ARIMA models, are difficult to configure if a complete analysis is carried out, but they almost always give good results for high-quality forecast for the medium and short term. Benvenuto D. et al. evaluated the ARIMA model for predicting the evolution of the COVID-19 pandemic in the world on the basis of 1.5-month dynamics (January-February, 2020) and came to the conclusion that a model with an integration order of d = 2 would be optimal [7]. However, further development of the pandemic in the world has been an exponential growth since March 2020. Attempts were made to select the parameters of the ARIMA model for the development of the epidemic in various countries. In particular, to describe the development of the COVID-19 epidemic in Iran, a model with the integration order of d = 3 (typical for very explosive growth of the process) is suitable [8], and for other countries (Italy, Thailand, South Korea), much lower [9]. However, it should be noted that such comparison for the selection of model hyperparameters is incorrect, since the development of the epidemic in these countries did not start simultaneously. Ribeiro M. H. et al. (2020) used the ARIMA model, but only as a reference forecasting tool, the results of which are compared with the results obtained using other methods [10].

Adaptive models of exponential smoothing are a popular tool for predicting the development of the spread of coronavirus infection. So Zhang Z. et al. [11] used the Holt-Winters multiplicative model, and in the study for choosing forecast models for different countries they use various specifications of adaptive smoothing models: Holt, Brown, etc. The Holt model was also used to predict the development of the COVID-19 epidemic in Nigeria [12]. Simple exponential smoothing was also used in the study of Elmousalami H. H. and Hassanien A. E. (2020) [13], and the multiplicative models of exponential smoothing (Holt-Winters) — Petropoulos F. and Makridakis S. (2020) [14]. The main drawback of all these works is the lack of an explanation of the choice of an appropriate specification of models, as well as the lack of an “explanation” of the selection of hyperparameters of forecasting models.

Thus, the analysis of the sources made it possible to determine using short-term forecasting methods for the development of the COVID-19 epidemic in Russia: the ARIMA model, the Holt-Winters exponential smoothing model, and the SIRD epidemiological model.

Materials and methods

For forecasting COVID-19 in the Republic of Bashkortostan and the Russian Federation on March 15, 2020 a memorandum was signed between the Bashkir State Medical University and the Ufa State Aviation Technical University on the creation of a project Office for the COVID-19 forecasting, which already have significant experience in conducting epidemiological studies [15]. To build development forecasts, we used the official data of Rospotrebnadzor on the daily and cumulative dynamics of new cases of COVID-19 infection, and for those who recovered and died between March 23 and May 10, 2020. To solve the problem of predicting the development of the COVID-19 epidemic in Russia, the following models were used: ARIMA, SIRD, the Holt-Wintes multiplicative model with an exponential trend.

The ARIMA model (*p*, *d*, *q*) generally has three hyperparameters that must be set to obtain the correct model specification: *d* is the order of taking the differences ($\Delta y_t = y_t - y_{t-1}$) from the time series yt until the series becomes stationary in the broad sense, that is, until the mathematical expectation and variance of the series becomes constant, and the covariance between any two values of the series depends on the time interval between them; *p* is the autoregression order (AR), which is equal to the lag of the delay of the previous values of the time series, on which at the moment the value of the same series y_t depends linearly; *q* is the order of the moving average (MA), which is equal to the lag of the lag of past statistically significant errors ε_t made at the previous forecasting time intervals.

As a result, this is general view of the ARIMA model used in this work:

$$\Delta^d y_t = \alpha_1 \Delta^d y_{t-1} + \dots + \alpha_p \Delta^d y_{t-1} - \beta_1 \varepsilon_{t-1} - \dots - \beta_q \varepsilon_{t-q} + \varepsilon_t,$$

where, $\Delta^d y_t$ — differences of the order d of a number of the total number of new cases of COVID-19 infection in the Russian Federation; p is the order of autoregression; q is the order of the moving average; ε_t — residual component at step t, α_i, β_i — model coefficients to be evaluated.

Also, to build a forecast in the Russian Federation, classic epidemiological model SIRD (Susceptible-Infected-Removed-Died) was used, which can be described by a system of differential equations:

$$\frac{dS(t)}{dt} = -\frac{\beta S(t) I(t)}{N}$$

$$\frac{dI(t)}{dt} = \frac{\beta S(t) I(t)}{N} - \gamma I(t) - \mu I(t)$$

$$\frac{dR(t)}{dt} = \gamma I(t)$$

$$\frac{dD(t)}{dt} = \mu I(t)$$

$$S(t) + I(t) + R(t) + D(t) = N$$

where S(t) are susceptible, those who have not yet been infected but can become infected, I(t) are infected, R(t) are those who have recovered (immunity has formed), D(t) are dead, N — the whole population, β — coefficient responsible for the probability of infection as a result of contact, γ = 1/T, coefficient responsible for the time of cure, T — disease time, μ — mortality rate from infection.

The construction of an epidemiological model requires an accurate assessment of the constant coefficients β, γ and μ. This is possible only if the epidemic develops under constant conditions, but the periods of introduction and weakening of quarantine measures change the conditions for its development. In this regard, the authors used the following technology for selecting the coefficients responsible for the probability of infection, the probability of cure, and the probability of death: a Search Grid was constructed where various combinations of parameters were selected in increments of 0.1, then a retrospective forecast was made 5 steps forward for all combinations of parameters from search grids and the obtained values were compared with the actual ones, the approximation error was calculated. As a result, those parameters were considered optimal for which they received the smallest error. Taking into account the knowledge of the selected parameters, we built a perspective forecast for 5 days in advance, believing in such a way that environmental conditions do not change during this period of time. For the next five days, the parameters were rebuilt again, etc. That is, for every five days, their model parameters were evaluated, so for May 10 in Russia: β = 0.0000000004, γ = 0.017, μ = 0.00053.

The choice of specification for the adaptive smoothing model was based on the study of the structure of the time series, which represents the dynamics of the development of the COVID-19 epidemic in Russia. Despite the fact that cycling in the infection in theory should not be, in practice, there is little impact of weekly periodicity, which can be explained as the work schedule of laboratories that perform testing and reduction of social connections on weekends. In this regard, for the short-term forecasting, the Holt-Winters multiplicative model was chosen with a cyclic period of 7 days and an exponential trend:

$$\tilde{x}_{t+\tau} = e^{(a_{0t} + a_{1t} \cdot \tau)} \cdot f_{t-l+\tau},$$

where $\tilde{x}_t + \tau$ is the forecast made at τ adaptation steps after t steps of model training, $f_{t-l} + \tau$ is the model correction for cyclicity with a period l, α_{0t} and a_{1t} are adaptable parameters.

To assess the quality of the forecast, the average approximation error was used:

$$MAPE_{series} = \frac{1}{n} \cdot \sum_{t=1}^{T} \left| \frac{y_t - \hat{y}_t}{y_t} \right| \cdot 100\%$$

where y_t are the actual values, $\hat{y}_t$ are the calculated (predicted) values, n is the number of observations in the time series.

Results

When constructing all three variants of the models, they encountered the main feature of the epidemic in Russia: the development of the epidemic in the regions on average lags behind the main focus of the spread of infection in Moscow by 2–3 weeks. In this regard, the models were trained separately for Moscow and aggregated for other regions, then the obtained forecasts were compiled. As a result of numerical modeling, to evaluate the coefficients of the SIRD epidemiological model, a reproductive base number R 0 = 2.9 was selected.

When constructing the ARIMA model for each time interval, we had to select our hyperparameters *p, d,* and *q*. So for the forecasting period from April 8 to April 14 (respectively, the period of model “training” 01.03.2020–07.04.2020), the best parameters were 0.3.1 (*d* = 3 indicates a sharp start to the explosive process characteristic of the development of the COVID-19 epidemic in the Russian Federation for this period), then the epidemic development process "went" into exponential growth, in connection with this, when building models on the forecast horizon April 15 — May 4, 2020. a similar series of data was logarithmized, and parameters were already selected on the logarithmic series: for the forecast period April 15–19 (training period 8/03–14/04) — 2,1,1 (Russia) and 1,2,1 (Moscow), from April 20 to April 28 (training period 15/03–19/04) — 3.1.0 (Russia) and 2.2.1 (Moscow), for the period from April 28 to May 4 (training period 21/03–28/04) — 1.2.0 (Russia) and 2.1.1 (Moscow). As can be seen for the forecasting period from April 28 to May 4 in Russia there was a rapid increase not only in the speed of the epidemic, but also in acceleration (on the logarithmic series, the order of taking the differences so that the process becomes stationary, that is, in fact, does not depend on time, equal to 2). Approaching the forecast period on May 5–10, the epidemic development process slowed down, no exponential growth trends were observed, and the orders of the ARIMA model became (3, 2, 2) according to Moscow and (1, 2, 2) to the data in other regions.

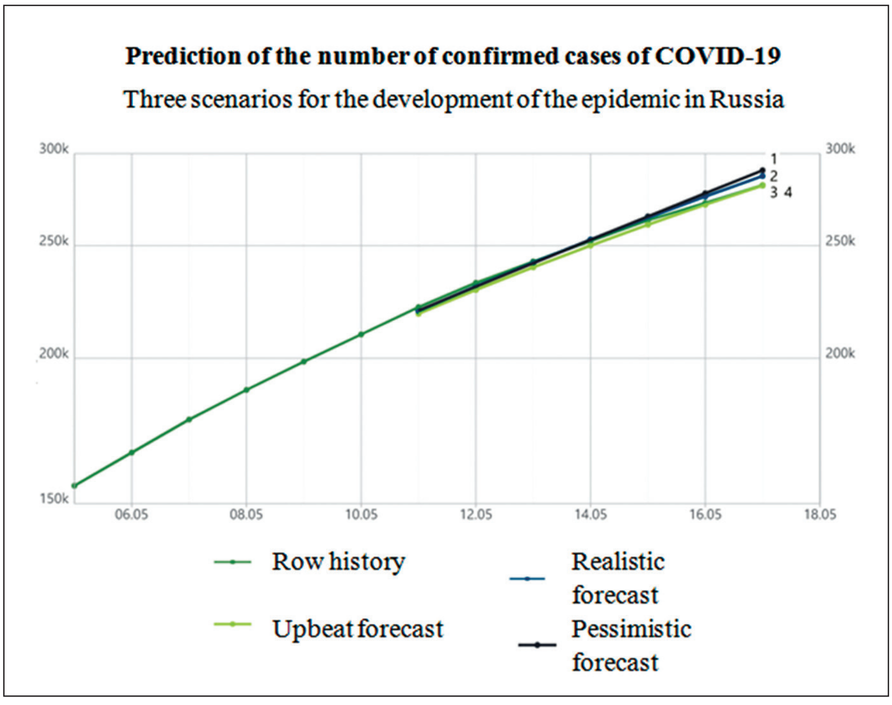
For the Holt-Winters model with an exponential trend, adaptation parameters were selected that are trained in a retrospective of the series for the forecast period from April 8 to May 4, 2020, based on the minimum average absolute percentage error, for the forecast period 5–10 May 2020, when slowdown development of COVID-19 epidemics was noted in the Russian Federation, used a linear trend.

The result of forecasting the total number of infected COVID-19 in the Russian Federation for all three models for the period May 11–17, 2020, as well as the calculated error as a percentage of the previous value for each date are summarized in table 1. Figure 1 shows the actual values and forecasts constructed in accordance with the three models proposed in the study.

Discussion and conclusion

The obtained forecasting results indicate a very high accuracy of the obtained forecasts, the difference in the forecast error in accordance with the three variants of application of the models is about 0.3 %. So in the period May 11–17, 2020 the average absolute percentage error according to the Holt-Winters model was 0.84 %, according to the SIRD model, which gives the most pessimistic forecast — 1.1 %, according to the ARIMA model — 0.8 %. The limitation of the applied methods and models should be noted: for example, the Holt-Winters model does not actually explain the essence of the epidemic development process, and exclusively focuses on the data themselves, in which there is a phenomenon of insignificant seven-day cyclicity, which is primarily associated not with the true development of the process infection, but with the work schedule of individual health services (testing laboratories, as well as administrative services). The use of the ARIMA model also required constant "further training" of the models at different stages of

Figure 1. Forecast of the development of the COVID-19 epidemic in Russia: 1 — in accordance with the SIRD model, 2 — in accordance with the Holt-Winters model, 3 — in accordance with the ARIMA model, 4 — actual values.



Таблица

TABLE 1. THE RESULTS OF FORECASTING IN ACCORDANCE WITH VARIOUS VERSIONS OF THE MODELS IN THE PERIOD MAY 11–17, 2020

2020 date	Incidence	SIRD		Holt-Winters		ARIMA	
		Forecast	Error	Forecast	Error	Forecast	Error
May 11	221344	219855	0,67 %	218468	1,30 %	219615	0,78 %
May 12	232243	230439	0,78 %	229005	1,39 %	230661	0,68 %
May 13	242271	241457	0,34 %	239538	1,13 %	241780	0,20 %
May 14	252245	252926	0,27 %	250073	0,86 %	252946	0,28 %
May 15	262843	264865	0,77 %	260608	0,85 %	264194	0,51 %
May 16	272043	277293	1,93 %	271143	0,33 %	275541	1,29 %
May 17	281752	290230	3,01 %	281679	0,03 %	286958	1,85 %

the epidemic, and each time it is necessary to change not only the estimated coefficients of the model, but also the number of model hyperparameters. In addition, although the ARIMA model showed the smallest discrepancy between the forecast and the actual data, this tool is well suited for short-term forecasting (up to 7 days), and it is preferable to use the SIRD epidemiological model or its modifications for a slightly more distant perspective of the planning horizon. A feature of the SIRD epidemiological model is that it takes constant values of the coefficients that are responsible for the probability of infection, the probability of cure, and the likelihood of death. However, the coronavirus epidemic in Russia requires the leadership of the country and regions to develop containment measures during its development, which affects the change in the trajectory of the epidemic, and as a result, the use of a similar model, the coefficients of which become variable, and their dynamic assessment is a separate task. In the article, the authors retrain the model coefficients according to the newly received data with a step of 5 days, which is justified for obtaining short-term forecasts (up to 10 days) of high accuracy.

Thus, the article shows the possibility of forecasting COVID-19 in the Russian Federation, the necessary mathematical tools are selected, the limitations of their use are indicated, and high accuracy for short-term forecasting is shown.

Forecasting results are regularly presented to executive authorities to consider strategies for the prevention of medical and quarantine measures. In addition, research results are regularly presented in the public domain at http://covid-forecast.ru/ for a wide range of medical and non-medical specialists and readers.

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Conflict of interest / Конфликт интересов

The authors declare no conflict of interest.
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References / Список литературы

1. Roosa K, Lee Y, Luo R, Kirpich A, Rothenberg R, Hyman JM, Yan P et al. Short-term forecasts of the COVID-19 epidemic in Guangdong and Zhejiang, China: February 13–23, 2020. J Clin Med. 2020;9(2):596. doi:10.3390/jcm9020596

2. Stübinger J, Schneider L Epidemiology of coronavirus COVID-19: forecasting the future incidence in different countries. Healthcare. 2020;8(2):99. doi:10.3390/healthcare8020099

3. Huang Y, Yang L, Dai H, Tian F, Chen K. Epidemic situation and forecasting of COVID-19 in and outside China. Bulletin of the World Health Organization. [Published online 16 March 2020]. doi:10.2471/BLT.20.255158

4. Sun D, Duan L, Xiong J, Wang D Modelling and forecasting the spread tendency of the COVID-19 in China. BMC Infectious Diseases. [Published online 8 May 2020]. doi:10.21203/rs.3.rs-26772/v1

5. Avila E, Canto FJA Fitting parameters of SEIR and SIRD models of COVID-19 pandemic in Mexico. [Published online 15 April 2020]. [Electronic resource]. URL: https://www.researchgate.net/publication/341165247_Fitting_parameters_of_SEIR_and_SIRD_models_of_COVID-19_pandemic_in_Mexico#fullTextFileContent

6. Prem K, Liu Y, Russell TW, Kucharski AJ, Eggo RM, Davies N et al. The effect of control strategies to reduce social mixing on outcomes of the COVID-19 epidemic in Wuhan, China: a modelling study. Lancet Public Health 2020;5(5):e261–270. doi:10.1016/ S2468-2667(20)30073-6

7. Benvenuto D, Giovanetti M, Vassallo L, Angeletti S, Ciccozzi M Application of the ARIMA model on the COVID-2019 epidemic dataset. Data Brief. 2020:1053403. [Ahead of print, published online 26 February 2020]. doi:10.1016/j.dib.2020.105340

8. Dehesh T, Mardani-Fard HA, Dehesh P Forecasting of COVID-19 Confirmed Cases in Different Countries with ARIMA

Models. MedRxiv. [Published online 18 March 2020]. doi:10.1101/2020.03.13.20035345

9. Yonar H, Yonar A, Tekindal MA, Tekindal M. Modeling and forecasting for the number of cases of the COVID-19 pandemic with the curve estimation models, the Box-Jenkins and exponential smoothing methods. Euras J Med Oncol. 2020;4(2):160–165. doi:10.14744/ejmo.2020.28273

10. Ribeiro MHDM, Gomes da Silva R, Mariani VC, Coelho Ld S. Short-term forecasting COVID-19 cumulative confirmed cases: Perspectives for Brazil. Chaos, Solitons and Fractals. 2020;135: 109853. doi:10.1016/j.chaos.2020.109853

11. Zhang Z, Wang X, Gong H, Liu X, Chen H, Chu Z et al. Daily tracking and forecasting of the global COVID-19 pandemic trend using holt–winters exponential smoothing. Lancet. [Published online 15 April 2020]. https://dx.doi.org/10.2139/ssrn.3564413

12. Abdulmajeed K, Adeleke M, Popoola L. Online forecasting of COVID-19 cases in Nigeria using limited data. Data Brief. 2020;30:105683. doi:10.1016/j.dib.2020.105683

13. Elmousalami HH, Hassanien AE. Day level forecasting for coronavirus disease (COVID-19) spread: analysis, modeling and recommendations. [Published online 15 March 2020]. [Electronic resource]. URL: https://arxiv.org/ftp/arxiv/papers/2003/2003.07778.pdf

14. Petropoulos F, Makridakis S Forecasting the novel coronavirus COVID-19. PLoS ONE 15(3):e0231236. doi:10.1371/journal.pone.0231236

15. Zagidullin N, Motloch LJ, Gareeva D, Hamitova A, Lakman I, Krioni I et al. Combining novel biomarkers for risk stratification of two-year cardiovascular mortality in patients with ST-elevation myocardial infarction. J Clin Med. 2020;9(2):550. doi:10.3390/jcm9020550

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