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# BRIEF REVIEW OF THE MATHEMATICAL MODELS FOR ANALYZING AND FORECASTING TRANSMISSION OF COVID-19

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**ABSTRACT:** Coronaviruses are one of the dangerous sources of human infection. To counter such a source, it is important to obtain reliable statistics. It is also necessary to carry out appropriate data analysis, which helps to find solutions to various issues. To do this, use data analysis and forecasting models. Thus, this work is devoted to the review of mathematical models for the analysis and prediction of the distribution of COVID-19. Such a review showed that there are models of different directions. This allows you to make more effective decisions.

**KEYWORDS:** mathematical models, analysis, forecasting, transmission, COVID-19

## I. INTRODUCTION

The ongoing COVID-19 outbreak poses a challenge for model designers, as there is limited data on pathway of virus, and epidemiological characteristics of new coronavirus are still not fully defined.

The transmission of an emerging novel respiratory pathogen is accompanied by uncertainty concerning its key epidemiological, clinical and virological characteristics, particularly its ability to transmission in human population and its virulence (case severity). This is case for novel coronavirus known as severe acute respiratory syndrome coronavirus [1].

COVID-19 has many characteristics that are different from other infectious diseases, including high infectivity during incubation, time delay between real dynamics and daily numbers of confirmed cases. This explains relevance of this work.

## II. THE MAIN TYPES OF MATHEMATICAL COMPONENTS FOR ANALYSIS AND FORECASTING

Three main types of mathematical components can be distinguished for analysis and forecasting: data analysis, modeling and forecasting.

Data analysis in COVID-19 field is engaged in construction and study of most common mathematical methods and computational algorithms (for example, flower pollination algorithm (FPA), sine-cosine algorithm (SCA), or salp swarm algorithm (SSA)) [2]. Data analysis helps prevent COVID-19 by managing outbreaks based on risk analysis and assessment, assessing transmission of virus, and clarifying mechanisms and emergency response plans; analysis of virus transmission nature and its features. Epidemic outbreaks can be controlled with help of emergency decision-making teams in epidemiological situation. Traditional methods of time series analysis are regression and autoregressive models; approaches based on machine learning – Bayesian networks and artificial neural networks.

Modeling is cyclical process that reflects trajectories of current COVID-19 pandemic. That is, study of most probable trajectory that pandemic will go and which can be predicted on mathematical model of main dynamics of infectious disease transmission in particular population. Simulation results reveal a consistent prevalence of COVID-19 with specific values for infected, recovered, and fatal cases. Thus, timeliness of COVID-19 prevention and control strategies using mathematical models and combining with a small amount of real-time updated data from several sources is key to preventing transmission of pandemic. The most important directions in transmission of COVID-19 propagation mathematical models: classical analytical models, deterministic and stochastic, as well as modern simulation models, network and agent ones.

As for modeling, mathematical models allow us to calculate such an important indicator – basic reproductive number (reproduction index) or number of patients who will be infected with one infected for entire period of his illness.

The number of works devoted to forecasting COVID-19 is growing rapidly with advent of statistics allowing analysis. Forecasting is carried out for different periods and, depending on them, serves different purposes. The short-term prognosis for several weeks in advance is used in operational management and in identifying outbreaks of COVID-19. The forecast will necessarily depend on assumptions underlying model. The most important can be considered a medium-term forecast for period of two months, used in tactical management, although it is less accurate than short-term, but leaves enough time to prepare for possible emergencies and take measures to prevent pandemic transmission.

COVID-19 pandemic datasets have become available to everyone and, more importantly, they are pre-grouped, which simplifies work with visualization and analysis tools. Thus, even non-professionals can work with them and receive reliable information about situation with coronavirus.

Today, there are extensive possibilities for data visualization, which can be further used to successfully simulate transmission process of COVID-19 [1], [3]-[6]:

- networks, simple and hierarchical;

- timelines, using date of onset, date of reporting or date of last contact;

- bar charts combining date of onset, hospitalization data, laboratory testing data and outcome.

Visualization during data analysis can be a prerequisite for reducing time of aggregation and data processing. By visualizing COVID-19 forecasting from real-time trackers, it expands availability of forecasts worldwide at state level, and also allows use of various methods of information processing, which also reduces time in determining a particular scenario for preventing COVID-19. The modeling process is process of transition from real domain to virtual (model) through formalization, then model is studied (modeling itself), visualization during simulation allows you to create a number of different parameter/variable chains representation, which predicts result based on choice of appropriate variant of modeling behavior [7].

A simple means of displaying composition and structure of any system are simple and hierarchical networks. It is much easier to perceive COVID-19 information using such schemes. The network is characterized by possibility of many different ways of moving along edges between some pairs of vertices.

Timelines visually displays transmission in time frame of most important events regarding COVID-19, which makes it easy to find necessary data for a specific period of time. Organizing data in this way allows you to simplify process of comparing data for specific dates of interest.

Bar chart allows you to visually assess transmission of statistical data, grouped by frequency of hits in a certain (predefined) interval. Such a presentation of data makes it possible to visualize trends in measured parameters.

## III. THE BASIC MATHEMATICAL MODELS FOR THE ANALYSIS AND FORECASTING OF DATA ABOUT COVID-19

The analysis of literary sources showed that among the main models for the analysis and forecasting of data about COVID-19 it should be distinguished:

1) Model SUQC. Quantitative assessment of parameters and variables of epidemic: “not quarantine”, “quarantine”, people with a confirmed diagnosis and transmission of virus. Modeling effects of quarantine and control measures [8]. Advantage – takes into account a parameter such as reproductive number, which is most discussed term in current COVID-19 pandemic. This number, denoted by R, refers to number of new infections that one infected person can cause in a susceptible population, and model may also be useful in predicting epidemic trend for high-population countries. A disadvantage of model is that model does not take confidence intervals into account. Model SUQC demonstrates accurate prediction and is not complex, with a short period of time to implement data analysis.

2) Model SIDR (Susceptible-Infectious-Recovered-Dead). Estimation of mortality and recovery rates for entire period using a sliding window lasting one day [9]. The model is presented in form of a network. Advantage – takes into account average number of secondary cases resulting from introduction of infection into a fully susceptible

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population during period of infection. Disadvantages – involves loss of data on each node. The model demonstrates not very accurate prediction, it is not complicated, with a short period of time for data analysis implementation.

3) Model SRID (Susceptible – susceptible, Recovered – recovered, Infectious – infected, Deceased – dead). Gives a forecast of virus transmission, taking into account statistical errors. Estimates epidemic forecasts in case of urgent anti-epidemic measures. Universal mathematical model. Built-in statistical assessment of confidence intervals for all investigated variables and epidemic process parameters. It provides for formation of a stable immunity to infection (re-infection is impossible). The main advantage of SRID models is that self-structure information of noisy image is exploited and trained dictionary is adaptive to images of interests. Hence these SRID are more effective than those learning dictionary in a training database [10], [11]. Disadvantages traditional SRID – low sensitivity, low throughput and need to create annual reference reagents. The model demonstrates not very accurate prediction, is not complicated, with a short turnaround time of data analysis. The model is not very simple, is inaccurate, time-consuming.

4) Model SIR (Susceptible – susceptible, Infectious – infected, Recovered – recovered). Gives a forecast of possible outbreaks of COVID-19 and their control. A model with formation of stable immunity. The model is expressed using stochastic differential equations. Modeling is performed by changing exposure factor over time to understand response of infection to blocking time schedule of more than 6 months. Impact factor: isolation, selective quarantine and preventive measures. The exposure coefficient, which models interventions to suppress transmission of infection, is also taken into account [12], [13]. Advantage – reflects a reassessment of predicted number of infections to compensate for undetected or undetected infections. Disadvantages – short lead-time. And second drawback of reproductive number is not included in model, although it can be calculated. The model is not particularly simple, in order to obtain accurate results using SIR models, in-depth information on social movements is necessary and quality of lockdown measures will be important. Lead-time increases, accuracy of model declines. In general, SIR-based models will be accurate.

5) Model SEIR. A model with formation of stable immunity. Stochastic (random) estimate. Statistical transmissions of number and duration of contacts. The model is based on use of empirical data from a dynamic network of contacts determined by collected data from RFID devices. Calculation of number of contacts, average duration of contacts, average degree of node (defined as number of individuals that a person encountered during study), average clustering coefficient (which describes local consistency), average shortest path (average distance traveled, which must be traveled to go from one node / destination to another) [12]. The SEIR model shows an advantage as it does not grow exponentially with time but also uses some intervention methods with time. Disadvantages such as that of SIR model is that reproductive number is not included in model, although it can be calculated. The model is not simple. More accurate predictions. The key reason why SEIR models are difficult to fit for COVID-19 is non-stationarity of mixing, caused by nudging (step-by-step) intervention measures. A further drawback of conventional epidemiological models is short lead-time.

6) Model SIS (Susceptible – susceptible, Recovered – recovered, Susceptible – susceptible). A model without stable immunity with possible chronic course of disease [14]. Advantage – takes into account fact that recovered people are resistant to re-infection. The disadvantage, as in SIS model – if described by differential equations, it is assumed that sick / healthy / immune are evenly distributed in space. The model is simple, it does not require much lead-time. Gives an average accurate prediction of virus transmission.

7) Model ABM. Agent based model. Model for detailed computer simulation COVID-19. This model is calibrated to reproduce main transmission characteristics of COVID-19. An important result of calibration is age-related proportion of symptomatic (infectious) cases, and this proportion for children is one fifth of that for adults [15]. AceMod simulator includes more than 24 million software agents, each of which has attributes of an anonymous person (for example, age, gender, occupation, susceptibility and immunity to diseases), etc. A set of generated agents captures average characteristics of a real population [16]. Advantages: because behavior and characteristics of each agent is independent, they can simulate complex dynamic systems with less oversimplification of rich variation among individuals; agents can be simulated in physical two- or three-dimensional spaces, they can better simulate geometry of contact between individuals, which is highly relevant in epidemiology. Disadvantage Model ABM – lack of transparency and interpretability (e.g., it is impossible to determine what imaging features are being used to determine output). The model is not simple (model is very detailed). More accurate predictions. Short lead-time.

Thus, seven basic types of mathematical models were considered above, one of main tasks which was to evaluate COVID-19 transmission. In these models, we are talking about determining numerical indicators of sick and infected COVID-19, and determining causal structure of epidemic: identifying factors that affect forecasting object, that is, finding relationship between a numbers of parameters is performed by qualitatively forecasting epidemic.

Models: SUQC, SIDR, SRID, SIR, SEIR, SIS, ABM, forecasting and prediction are mathematical models of COVID-19 transmission. A certain difficulty in forecasting is fact that in studied area there are no established laws, there are patterns and trends. That is why ready-made forecasts are carefully analyzed, worked out and adjusted ex post.

It is impossible to accurately predict COVID-19 transmission, but forecasts can be improved by adjusting mathematical models, refining input data, and comparing forecasts with each other. But in general, you can determine accuracy:

- calculating indicator forecast accuracy – an estimate of how much exactly selected model describes data being analyzed;

- graphical analysis – a graph is built and adequacy of forecast model relative to actual COVID-19 transmission over last period is visually assessed.

## IV. MODELS FOR PREDICTION AND FORECASTING THE TRANSMISSION OF THE COVID-19 PANDEMIC

1) Real-time forecasting (forecast) – model is used to create and evaluate short-term forecasts (for example, a period of 3 days) of total number of confirmed recorded cases [16], [17]. The model predicts that epidemic has reached a saturation point. The projections presented are based on assumption that ongoing mitigation efforts will continue. The advantage of this model is that it can take into account different age categories of population and seasonality. Disadvantage is inability to make a forecast for a long period. To improve accuracy of sales forecasts, it is important to understand that different forecasting models are suitable for different time frames with different characteristics. Unfortunately, there is no one model that would be suitable for calculating forecast for all situations – types of time series.

2) Real-time forecasting based on artificial intelligence (AI) is a more accurate forecasting model. Estimation of size, length and end time of COVID-19 in different countries. A modified complex auto-encoder for modeling propagation dynamics [18]. In real-time forecasting based on artificial intelligence, an accurate domain model is needed. Advantage – model can identify new cases of COVID-19 with 96 % accuracy. Disadvantage is high complexity. Reasoning based on such models is usually carried out at a detailed level, which leads to significant complications.

3) Real-time prediction. Real-time evaluation of COVID-19 transmission. Changes in dynamics of incidence rate for infected, deceased, and recovered people, so that it is possible to naturally adapt to adaptive changes in real time to mitigate effects of diseases, business activity, and social behavior of population [19]. The advantage is relative prostate model of its computational implementation. Disadvantage is that COVID-19 “acts unpredictably,” harming some groups more than others – local demography and healthcare has a very strong influence on outcome, and indeed on accuracy of predictions.

## V. CONCLUSION

The work provides a comparative analysis of existing models for analyzing and predicting transmission of COVID-19, which allows you to clearly highlight features of modeling.

A review showed that existing models of different directions. However, a common feature is analysis and evaluation of COVID-19 transmission. Such a review is necessary to analyze features of existing models and methods, and this will become a prerequisite for further transmission of more accurate models for estimation and forecasting.

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