

Dmytro CHUMACHENKO¹, Tetyana CHUMACHENKO², Nataliia KIRINOVYCH¹, Ievgen MENIAILOV³, Olena MURADYAN³, Olga SALUN²

¹ National Aerospace University “Kharkiv Aviation Institute”, Kharkiv, Ukraine

² Kharkiv National Medical University, Kharkiv, Ukraine

³ V. N. Karazin Kharkiv National University, Kharkiv, Ukraine

BARRIERS OF COVID-19 VACCINATION IN UKRAINE DURING THE WAR: THE SIMULATION STUDY USING ARIMA MODEL

The COVID-19 pandemic has become a challenge to public health systems worldwide. As of June 2022, more than 545 million cases have been registered worldwide, more than 6.34 million of which have died. The gratuitous and bloody war launched by Russia in Ukraine has affected the public health system, including disruptions to COVID-19 vaccination plans. The use of simulation models to estimate the necessary coverage of COVID-19 vaccination in Ukraine will make it possible to rapidly change the policy to combat the pandemic in the wartime. This study aims to develop a COVID-19 vaccination model in Ukraine and to study the impact of war on this process. The study is multidisciplinary and includes a sociological study of the attitude of the population of Ukraine toward COVID-19 vaccination before the escalation of the war, the modeling of the vaccine campaign, forecasting the required number of doses administered after the start of the war, epidemiological analysis of the simulation results. **This research targeted** the COVID-19 epidemic process during the war. The research **subjects** are the methods and models of epidemic process simulation based on statistical machine learning. Sociological analysis **methods** were applied to achieve this goal, and an ARIMA model was developed to assess COVID-19 vaccination coverage. As a result of the study, the population of Ukraine was clustered in attitude to COVID-19 vaccination. As a result of a sociological study of 437 donors and 797 medical workers, four classes were distinguished: supporters, loyalists, conformists, and skeptics. An ARIMA model was built to simulate the daily coverage of COVID-19 vaccinations. A retrospective forecast verified the model's accuracy for the period 01/25/22 - 02/23/22 in Ukraine. The forecast accuracy for 30 days was 98.79%. The model was applied to estimate the required vaccination coverage in Ukraine for the period 02/24/22 – 03/25/22. **Conclusions.** A multidisciplinary study made it possible to assess the adherence of the population of Ukraine to COVID-19 vaccination and develop an ARIMA model to assess the necessary COVID-19 vaccination coverage in Ukraine. The model developed is highly accurate and can be used by public health agencies to adjust vaccine policies in wartime. Given the barriers to vaccination acceptance, despite the hostilities, it is necessary to continue to perform awareness-raising work in the media, covering not only the events of the war but also setting the population on the need to receive the first and second doses of the COVID-19 vaccine for previously unvaccinated people, and a booster dose for those who have previously received two doses of the vaccine, involving opinion leaders in such works.

Keywords: epidemic model; epidemic process; epidemic simulation; simulation; COVID-19; ARIMA; war.

Introduction

Coronavirus Disease 2019 (COVID-19) is a potentially severe acute respiratory infection caused by the SARS-CoV-2 coronavirus. COVID-19 can occur as an acute respiratory viral infection of a mild course or a severe form. The virus can infect various organs through direct infection or the body's immune response. Complications include viral pneumonia, acute respiratory distress syndrome, acute respiratory failure, multiple organ failure, septic shock, venous thromboembolism, and others [1].

The outbreak began in December 2019 in Wuhan, China. On March 11, 2020, the WHO declared the outbreak a pandemic. As of June 2022, more than 545 million cases have been registered worldwide, more than

6.34 million of which have died.

The global pandemic has also stimulated the development of research on using digital tools to control epidemic processes. Many scientific groups have focused on the development of data-driven tools for diagnosing morbidity [2], data processing [3], research on external factors [4], social impacts on a pandemic [5], medical data security [6], etc.

Vaccination is the most effective way to protect yourself from COVID-19, prevent the spread of new strains, and stop the pandemic. Vaccination protects against severe illness, hospitalization, and death if infected with COVID-19 [7]. Since April 2020, medical institutions and pharmaceutical companies have developed and tested more than 40 vaccines against COVID-19. Mass vaccination against COVID-19 began in December

2020 in the United States and several other countries. As of June 2022, almost 12 billion vaccine doses have been administered worldwide, 5.2 billion people have been vaccinated with at least one dose, and 4.7 billion have completed the entire course of vaccination [8]. In Ukraine, the vaccination campaign started on February 24, 2021.

Exactly one year later, on February 24, 2022, Russia started a war in Ukraine for no reason. In addition to colossal destruction and human casualties, the war brought a humanitarian crisis to Ukraine, which also affected the public health sector. In particular, the war also affected the spread of viral diseases. Active hostilities, the temporary occupation of certain regions by Russia, and the redistribution of healthcare resources for military needs have practically stopped the vaccine campaign against COVID-19. At the same time, at the start of the war, Ukraine was at the stage of increasing incidence [9].

The study aims to develop a vaccination model against COVID-19 in Ukraine and to study the impact of war on this process. The study is multidisciplinary and includes a sociological study of the attitude of the population of Ukraine to vaccination against COVID-19 before the escalation of the war, modeling of the vaccine campaign, and forecasting the required number of doses administered after the start of the war, epidemiological analysis of the simulation results. The research is targeted at the COVID-19 epidemic process during the war. The research subjects are methods and models of epidemic process simulation based on statistical machine learning.

To achieve the aim of the research following tasks have been formulated:

1. Methods and models of the COVID-19 vaccination should be analyzed;
2. Method of the sociological estimation of attitude to vaccination against COVID-19 in Ukraine should be developed;
3. A simulation model of the COVID-19 vaccination based on autoregressive integrated moving average (ARIMA) method should be developed;
4. Verification of ARIMA model should be provided;
5. Sociological investigation on COVID-19 vaccination attitude in Ukraine should be provided;
6. Estimation of COVID-19 vaccination plan during the first month of the war in Ukraine should be provided;
7. Results obtained during the experimental studies should be analyzed.

The respective contribution of this study is threefold. Firstly, the cluster analysis of attitude toward vaccination against COVID-19 in Ukraine based on sociological approaches will allow correcting the vaccination policies. Secondly, the development of ARIMA model will allow estimating the accuracy of simple machine

learning methods applied to the simulation of the COVID-19 vaccination dynamics in Ukraine. Thirdly, simulation results will allow us to assess the actual state of the COVID-19 vaccination in Ukraine during the war, which will allow us to identify the necessary measures to combat the pandemic.

In this paper, section 1, namely the current research analysis, provides the current state of COVID-19 vaccination strategies simulation methods and models. Section 2, namely Data Analysis, describes the background of the vaccination against COVID-19 in Ukraine and analyses the data sources used in the research. Section 3, namely Materials and Methods, provides a methodology of sociological research, a brief overview of the ARIMA model, and verification methods of the prognostic models. Section 4 provides the results of cluster analysis of attitude toward vaccination in Ukraine, verification of the model of vaccination against COVID-19 in Ukraine, and estimation of necessary vaccination plan in Ukraine during the war. The discussion section discusses the obtained results from the epidemiology view. Conclusions describe the outcomes of the investigation.

Given research is part of a project on development of complex intelligent information system for epidemiological diagnostics, the concept of which is discussed in [10].

1. Current Research Analysis

In this article, we are investigating the COVID-19 vaccine campaign in Ukraine, so it is necessary to review existing studies to model COVID-19 vaccination.

The paper [11] reviewed a COVID-19 model with a double-dose vaccination strategy for outbreak control in Bangladesh. Modeling is based on a compartmental approach. The study results show that the full-dose vaccination program significantly reduces the number of mild and critical cases and can potentially contribute to eradicating the virus in a particular area. The study [12] also proposes a compartmental approach to model COVID-19 given vaccination. The authors show that the critical vaccination threshold depends on the vaccine's effectiveness in eradicating the disease at any time, even if vaccination coverage is high. The results of a pilot study on cumulative incidence data in Senegal show that despite the effectiveness of vaccination and treatment of COVID-19, additional efforts, such as non-pharmacological public health interventions, should continue to mitigate the spread of the virus. The authors of [13] propose a deterministic compartmental model and a stochastic branching process model to assess the impact of the deployment of a vaccine campaign in New Zealand on the potential spread and health impact of COVID-19. A threshold for required vaccination to contain the current pandemic has

been calculated. However, since such coverage is unlikely to be achievable in practice, complete relaxation of control could lead to severe consequences for spreading the virus. However, the study shows that the higher the vaccination coverage, the greater the herd immunity in the population, and the easier it will be to control new outbreaks.

The study [14] aims to investigate the reasons for accepting or rejecting COVID-19 vaccines among the Malaysian population. As a result of modeling based on a sociological study, the authors show that the majority of respondents consider the vaccine to be safe, effective, protective, and provide herd immunity. At the same time, an obstacle to vaccination is unknown long-term side effects, the rapid production of the vaccine, and the fear of halal status.

The authors of [15] propose a mathematical model of COVID-19 to assess the short-term impact of various vaccination scenarios in Lebanon. Simulation results have shown that vaccination has an impact in the short term. Expansion must be rapid and achieve high coverage (at least 70%) while maintaining social distancing measures during deployment. The work [16] proposes a model of the COVID-19 epidemic to predict the effectiveness of vaccination in the United States. The model analyzes the effectiveness of vaccination in terms of vaccination effectiveness, vaccination planning, and relaxation of social measures that reduce disease transmission. Modeling results show that reducing the epidemic as vaccination is introduced depends critically on the extent to which social measures that reduce transmission of the disease are eased.

The article [17] is devoted to studying the effect of vaccines that have different efficacy after the first dose and after the second dose regimen, considering the different efficacy against severe disease and not against widespread infection. The model aims to investigate the effect of the vaccine in reducing hospitalizations in a short-term scenario in Spain, with a population under mixed vaccination conditions. Modeling results justify the population coverage needed to achieve herd immunity. The study [18] aims to develop a deterministic compartmental epidemic response model with limited supply and mass vaccination to evaluate vaccination scenarios in New South Wales, Australia. The simulation results showed that herd immunity is possible with the vaccination of 66% of the population. At the same time, using vaccines with an efficiency of less than 70% cannot provide herd immunity and will lead to a constant risk of outbreaks.

Article [19] proposes a stochastic compartmental model for evaluating the effectiveness of a vaccine against the symptomatic disease. Using the model, experiments were carried out for three scenarios, distinguishing between the vaccine's effectiveness against infection,

infectivity, and symptoms. As a result, the authors conclude that the vaccination of medical personnel is essential for their protection and for reducing the number of cases among residents of nursing homes. The authors of [20] discuss how the models have been applied to health policy decisions related to COVID-19 vaccination and how they can be applied in the future in the context of booster doses under various scenarios associated with specific disease factors. The article shows that combining segmental and network models can improve the power and reliability of epidemiological forecasts.

Review [21] considers epidemiological and economic modeling data for priority populations to minimize mortality, transmission, and incidence of COVID-19. The analysis results confirmed the recommendations of WHO regarding the priority of vaccines against COVID-19. However, there is a gap in data on optimal prioritization for low- and middle-income countries.

Analysis of studies showed that most scientific groups use a compartmental approach to model vaccination against COVID-19. However, the lack of disparate data on the war conditions in Ukraine does not allow applying the approach for modeling on the territory of the country. Therefore, this article proposes developing a COVID-19 vaccination model using statistical machine learning methods.

2. Data Analysis

2.1. Background on Vaccination against COVID-19 in Ukraine

Vaccination against COVID-19 in Ukraine began on February 24, 2021, after the development and availability of vaccines against COVID-19 for emergency use. Preparations for the start of the vaccine campaign were carried out taking into account the recommendations of WHO, which in its documents emphasized that national strategies for vaccination against COVID-19 should be adapted taking into account the characteristics of the country's health systems and national context, the volume and pace of vaccine supply and characteristics and risk assessment - benefits for various population groups [22]. In Ukraine, potential target groups and vaccination strategies have been identified and a Roadmap for vaccination of the population of Ukraine [23] has been developed to achieve the following goals:

- to reduce the number of deaths associated with COVID-19 coronavirus disease;
- to reduce the severity and number of health complications associated with COVID-19.

It was determined that the main objective of the Roadmap for vaccination during 2021-2022 is to cover at least 50% of the population of Ukraine (20,866,390 people) with vaccination against the coronavirus disease

COVID-19. Voluntary vaccination against COVID-19 was envisaged for all population groups and occupational groups.

Approaches to the implementation of a vaccination program are largely dependent on the availability of vaccines. At the start of the vaccine campaign, production capacity was unable to meet all of the global demand for a COVID-19 vaccine. Global demand was predicted to outstrip the vaccine production capacity of manufacturers throughout 2021 and 2022. Therefore, based on the recommendations of WHO, SAGE 17, and ETAGE, the Preliminary Framework for the Equitable Distribution of the COVID-19 Vaccine (The National Academy of Sciences, Engineering, Medicine, USA), the recommendations of the National Immunization Technical Expert Panel of Ukraine, it was recommended to allocate nine priority groups for COVID-19 disease, including (in order of priority for access to vaccination) [24, 25]:

1. Medical workers, including those directly involved in measures to counter the COVID-19 coronavirus disease pandemic.

2. Military personnel (including the Armed Forces of Ukraine and the National Guard of Ukraine) participating in the Joint Forces Operation.

3. Social workers, including social workers.

4. Persons living in institutions providing long-term care and support, and employees of such institutions.

5. The elderly (60 years and older), including those with comorbidities who are at risk of developing complications and death due to COVID-19 disease (people diagnosed with diseases of the endocrine system, cardiovascular diseases, chronic diseases respiratory tract, chronic diseases of the nervous system, chronic diseases of the urinary system, oncological diseases, chronic diseases of the hematopoietic organs and blood).

6. Employees of critical state security structures, including the State Emergency Service of Ukraine, the National Police of Ukraine, the National Guard of Ukraine, the Security Service of Ukraine, military personnel of the Armed Forces of Ukraine, the Ministry of Internal Affairs.

7. Teachers and other education workers.

8. Adults (aged 18 to 59 years) with comorbidities who are at risk of developing complications and death due to COVID-19 disease (people diagnosed with diseases of the endocrine system, cardiovascular diseases, chronic respiratory diseases pathways, chronic diseases of the nervous system, chronic diseases of the urinary system, oncological diseases, chronic diseases of the hematopoietic organs and blood).

9. People who are in places of restriction of freedom and/or pre-trial detention centers and employees of places of restriction of liberty and/or pre-trial detention centers.

When developing the National Plan for the Introduction of the Vaccine and Conducting Mass Vaccination against COVID-19, 4 stages were envisaged, indicating the exact timing, volumes of vaccination, and target groups, later a 5th stage was added, which included the vaccination of other categories of the population that were not included in the first four stages. It was assumed that one target group would be vaccinated during one stage, vaccination was carried out on two platforms - mobile and mobile teams and in primary health care facilities. Later, Mass Vaccination Centers were organized, where the population could also be vaccinated against COVID-19.

The peculiarities of the vaccination campaign in Ukraine were a large target group, which required priority vaccination against COVID-19, comprising more than 50 % of the population of Ukraine; the expected duration of vaccination; the use of new vaccines in the world obtained by new technologies; overburdened healthcare system. The process of organizing vaccination in Ukraine in response to the pandemic was organized and managed by the Ministry of Public Health and the Center for Public Health, a strong vertical coordination was built with direct supervision of the introduction of vaccination and feedback. At each stage, consultations were held with the regions, flexibility was provided only within the framework of approved scenarios, and responsibility for each decision was clearly articulated. These were the key principles for organizing vaccination against COVID-19 in Ukraine.

The vaccination course included two doses of the vaccine, which were administered at intervals of 4-12 weeks, depending on the type of vaccine.

On December 22, 2021, revaccination was introduced in Ukraine - a booster dose of the COVID-19 vaccine for medical workers and workers in residential care homes. She began to vaccinate on December 24th. All vaccinated, regardless of the target group, were able to receive a booster dose of the vaccine on January 6, 2022.

On February 2, 2022, the Cabinet of Ministers of Ukraine adopted the National COVID-19 Vaccination Plan for 2022, according to which the overall strategy for COVID-19 vaccination began to consist of a booster dose for those who had already received the basic vaccination course in 2021, and vaccination of those who did not receive a single dose. Additionally, in 2022, it was planned to cover children and adolescents aged 12 to 18 with vaccinations. The document also provided for the obligation of the regional and Kyiv city state administrations to ensure vaccination coverage of minors and at least 70 % of adults, including 80 % of people over 60 years of age. Particular attention continued to be given to those at risk. In addition, the document has a norm that provides for the creation of regional interdepartmental coordination commissions for its implementation and the approval of

regional vaccination plans for 2022.

Also in Ukraine, the supply of vaccine preparations was established, which made it possible to freely obtain the required dose of vaccine for the population of Ukraine.

Despite the efforts made, as of February 23, 2022, a year after the start of the vaccination campaign, 15,712,650 people were vaccinated in Ukraine, of which 15,712,648 people received the first dose, 15,175,097 people received two doses received an additional dose – 27,458 people, a booster dose – 701,836 people. A total of 31,617,039 vaccinations were done. At the same time, on February 23, 2022, 25,062 new cases of COVID-19 were registered, 297 deaths and 3,140 people were hospitalized.

2.2. Data Sources Analysis

To build a model of vaccination against COVID-19, data from the open WHO Coronavirus (COVID-19) Dashboard of the World Health Organization [8] were used. The database contains data on the incidence, mortality, and vaccination against COVID-19 in the world. Data for Ukraine comes from the Public Health Center under the Ministry of Health of Ukraine. The data for Ukraine does not include morbidity, mortality, and vaccination in the territory of Crimea and the territories of the Donetsk and Luhansk regions occupied by Russia until February 24, 2022. Data on vaccination against COVID-19 in Ukraine was not disclosed after the escalation of the war. Therefore, vaccination data from February 24, 2021, to February 23, 2022, were used to build the model.

3. Methods and Models

3.1. Sociological Investigation

The sociological part of the research deals with quantitative survey methods – face-to-face interviews with plasma donors (437 donors were interviewed) and medical staff (797 healthcare workers were interviewed) were conducted in the Kharkiv region from July to October 2021. The topic of the interview was the perception of the argumentation strategies for the introduction of mass vaccination (respondents were offered some statements about vaccination, which they could rate on a scale from “1 – strongly disagree” to “5 – strongly agree”):

1. The safety of vaccination.
2. Compulsory vaccination.
3. Efficiency.
4. Alternative vaccination.

(Dis)agreement with pro- and anti-vaccination statements showed the chances for the conscious embodiment of discursive practices in real social practices (in N. Fairclough terminology) of vaccination. And the focus

on groups of donors and health workers is explained by the high level of involvement in vaccination discourse, so we can consider them as potential opinion leaders. The medical staff acts as representatives of evidence-based (“official”) medicine, has significantly grown since the beginning of the pandemic authority, and thus can form specific beliefs and positions on certain aspects of the pandemic. In this case, doctors are an influential agent in the formation of certain attitudes in the mass consciousness about vaccination. On the other hand, healthcare workers as representatives of the professional community are more likely than others to encounter SARS-CoV-2, and, accordingly, are more involved in immunization processes. In turn, plasma donors do not belong to the professional field of healthcare but are quite strongly associated with it in their everyday life. That is, they can be considered the most included non-professionals in the medical discourse, who have a great articulatory potential in the vaccination discourse.

So, we suppose to receive a relief date with the difference between the perception of vaccination by healthcare workers and those who are not involved in the medical system as a professional, but who are quite active and can have potential social influence. This will provide a more accurate picture of the prospects for vaccination in terms of social factors and possible social barriers. Surveys of two different social groups in terms of their involvement in the medical sphere will allow balancing the potential deviations due to the characteristics of each group. We will increase the value of the data since we analyze groups that can both act as “locomotives” of the ideological and informational promotion of vaccination if it is supported in the group consciousness, and prevent such promotion from broadcasting a negative attitude towards vaccination.

3.2. ARIMA Model

The ARIMA model is a time series forecasting method. Modeling is carried out by regressing the dependent variable only by its lag value, the current value, and the random error term's lag value in converting non-stationary time series to stationary time series [26].

The ARIMA model includes the following main steps:

- trial model identification;
- estimation of model parameters;
- diagnostic verification of model adequacy;
- using the forecasting model.

The ARIMA model combines AR (Autoregressive), and MA (Moving Average) approaches. Therefore, the model consists of three parts:

- AR (Autoregressive) is a regression model that uses the dependence between observations and the number of integrated observations p .

–I (Integrated) provides stationarity by calculating the differences d .

–MA (Moving Average) analyzes the relationship between observations and residuals when applying the model to integrated observations q .

Thus, the simple form of the p -order autoregressive model is:

$$AR(p) = c + \sum_{i=1}^p \varphi_i x_{i-1} + \epsilon_i, \quad (1)$$

where x_i are a stationary variable;

c is a constant;

φ_i are autocorrelation coefficients;

ϵ_i are white noise with zero mean.

The moving average order model q has the form:

$$MA(q) = \mu + \sum_{i=1}^q \theta_i \epsilon_{i-1}, \quad (2)$$

where μ is the mathematical expectation of the process;

θ_i are weights;

θ_0 is assumed to be 1;

ϵ_i are white noise with zero mean.

Thus, the ARIMA model of order p, q is a combination of (1) and (2), and has the form:

$$ARIMA(p, q) = c + \sum_{i=1}^p \varphi_i x_{i-1} + \epsilon_i + \sum_{i=1}^q \theta_i \epsilon_{i-1}. \quad (3)$$

The parameters p and q are called the order of AR and MA. Using ARIMA allows you to make predictions on non-stationary data due to the introduction of integration into the model. This is achieved by taking differences.

To tune the model, the data is checked for stationarity and compliance with the moving average. The initial data analysis prepares them for forecasting by determining the parameters p, d , and q . As a training sample, we used data on vaccination against COVID-19 in Ukraine from February 24, 2021 (the start date of the vaccine campaign against COVID-19 in Ukraine) to January 24, 2022. The test sample compiled data from January 25, 2022, to February 23, 2022.

3.3. Model Performance Estimation

The model accuracy estimate is calculated using mean absolute percentage error:

$$MAPE = \frac{100\%}{n} \sum_{t=1}^n \left| \frac{A_t - F_t}{A_t} \right|, \quad (4)$$

where A_t is the actual value;

F_t is the forecasted value.

To assess the forecast of the vaccination doses of COVID-19 for the period of the war, the deviations of the forecasted data from the registered doses were calculated:

$$D = |F_t - A_t|, \quad (5)$$

where A_t is the actual value;

F_t is the forecasted value.

4. Results

4.1. Cluster Analysis of Attitude Toward Vaccination

Based on pre-war sociological research of different target groups (healthcare workers and plasma donors), a cluster analysis of attitudes towards vaccination was conducted [27, 28], four clusters were allocated:

1. Supporters – have an active pro-vaccination position, and maintain obligatory mass vaccination. There are 15-18% in the sample of health workers, but in the sample of donors this cluster turned out to be statistically insignificant.

2. Loyalists – also have the pro-vaccination position, but only on the individual level: they support vaccination as a personal decision and reject its mandatory or propaganda. In donors' clusters, there are 26-29 % of Loyalists, and in healthcare workers' cluster are 37-40 %.

3. Conformists – passive about vaccination, do not have a definite position, will be guided by the requirements of superiors and/or government. This cluster in the plasma donor sample occupies 40-43 %, and in the healthcare workers sample – 10-13 %.

4. Sceptics – reject both mandatory and propaganda of vaccination; in the group of donors, there are 40-43% of Sceptics, and in the group of health workers – only 10-13%. The obvious professional attitude of medics significantly reduces the number of those who doubt the importance/necessity of vaccination. But even in the most included in medicine sphere philistine, the number of Sceptics is approaching half. It is a cluster with the greatest social treats in the chain of social authority and opinion-leading. Correlation shows that mainly these are people with secondary specialized education, occupying low positions, and their average age is 4-5 years lower than that of the rest. We consider each cluster as an additional factor that enhances the effectiveness of vaccination at the general social level.

4.2. Model Verification

An ARIMA machine learning model for predicting the vaccination of COVID-19 was implemented JavaScript. For an experimental study, data on daily vaccination in Ukraine were used. We used World Health Organization Coronavirus Dashboard as a data source [8]. As a training sample, we used vaccination data in Ukraine from February 24, 2021, i.e., the start of the vaccination

campaign. For the test sample, we used data for 30 days before the beginning of the escalation of the Russian war in Ukraine (25.01.2022 – 23.02.2022).

Figure 1 shows the results of retrospective forecasting of cumulative vaccination doses against COVID-19 in Ukraine from January 25, 2022, to February 23, 2022. Forecasts were calculated for 7, 10, 20, and 30 days to illustrate the change in the forecast error with the increasing period.

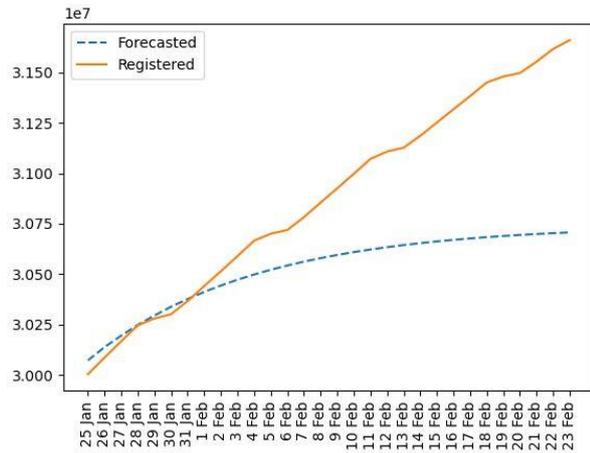


Fig. 1. Forecasting of COVID-19 vaccination doses in Ukraine (25.01.22 – 23.02.2022)

Table 1 shows model accuracy rates for cumulative vaccine doses of COVID-19 in Ukraine for a sample from January 25, 2022 to February 23, 2022.

Table 1
MAPE of forecast for 25.01.22 – 23.02.22 (%)

Duration of forecast (days)	MAPE
7 days	0.10053 %
10 days	0.14161 %
20 days	0.57879 %
30 days	1.18705 %

As the prediction results show, our hypothesis about the high accuracy of simple statistical machine learning models was confirmed. Forecast accuracy is sufficient for a long-term forecast of 30 days for vaccination dynamics.

4.3. COVID-19 Vaccination Estimation during War

To assess the necessary quantity of COVID-19 vaccination doses in Ukraine during the war, we applied the developed model to a sample of cumulative quantity of vaccine doses against COVID-19 to build a forecast from February 24, 2022, to March 25, 2022. Figure 2 shows the forecast of cumulative vaccine doses against COVID-

19 in Ukraine. Unfortunately, vaccination data from February 24, 2022 is not publicly available.

An assessment of the forecast for the wartime period shows that the forecasted vaccination doses against COVID-19 in Ukraine do not reflect the actual situation.

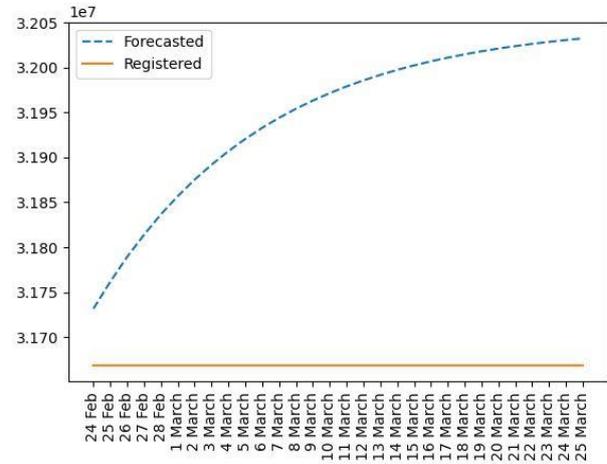


Fig. 2. Forecasting of COVID-19 vaccination doses (24.02.22 – 25.03.2022)

Figure 3 shows the deviation of daily forecasted vaccination doses against COVID-19 in Ukraine from the last available data on vaccination in Ukraine for the period from February 24, 2022, to March 25, 2022.

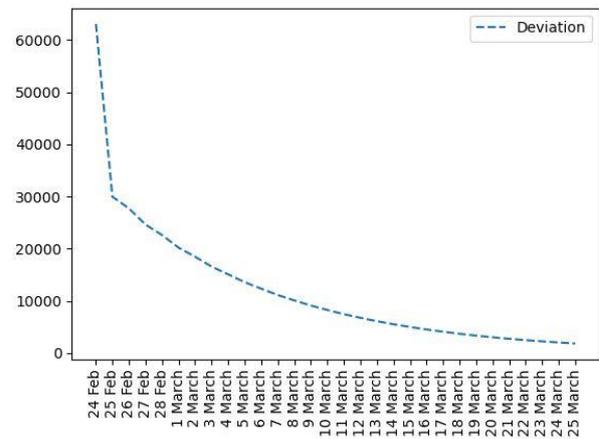


Fig. 3. Deviation of COVID-19 daily forecasted vaccination doses from last registered values (24.02.22 – 25.03.2022)

The data presented in Figures 2 and 3 is a projection of the required COVID-19 vaccination capacity during the escalation of the war. Because vaccination data is not available since February 24, 2022, the calculated predictive values can be used as a vaccination plan when making decisions about controlling the epidemic process of COVID-19.

5. Discussion

The COVID-19 pandemic has become a severe challenge to humanity. As of June 2022, more than 545 million cases have been registered worldwide, more than 6.34 million of which have died.

A significant achievement in the fight against the pandemic has been the development of safe and effective vaccines among non-pharmaceutical methods to contain the spread of the virus. To select the optimal and rational methods for controlling the epidemic process of COVID-19, such a tool as mathematical modeling is widely used. This method has proven itself to predict the dynamics of the spread of infection [29], determine the necessary immune layer [30], identify factors affecting the dynamics of the epidemic process [31], evaluate the effectiveness of quarantines [32], pharmacological [33] and non-pharmacological interventions to reduce the incidence.

Based on a time series analysis of COVID-19 vaccination, the model presented in this study allows it to be used for decision-making in public health institutions with limited data for planning COVID-19 vaccination policy during the Russian war in Ukraine. The model showed what level of vaccination is needed to mitigate the COVID-19 pandemic in the context of the war in Ukraine.

After Russia's unprovoked attack on Ukraine, Ukrainian healthcare was forced to devote all its efforts to helping wounded service members and the affected population. The civilian population suffered from mine and gunshot wounds, shell shock, mental attacks, mental health disorders, heart attacks, strokes, and other pathologies associated with the war. The volume of medical care that medical workers had to provide increased significantly. In addition, some medical workers, saving their lives and the lives of their families, moved to other regions of the country and foreign countries, which reduced the capacity of healthcare institutions. Many hospitals, dispensaries, diagnostic laboratories, and other health care facilities were destroyed. The attention of medical workers has switched from issues related to implementing preventive and anti-epidemic measures to contain the COVID-19 pandemic to addressing issues related to the increase in the flow of the wounded and sick.

Attacks on medical facilities and the destruction of healthcare infrastructure are forcing people to refuse to seek medical care [35] and reducing the possibility of implementing a full-scale vaccine campaign against COVID-19 [36].

Our research has shown that the population has different adherence to vaccination. Continued information attacks by Russian propagandists contribute to refusals to vaccinate even in those territories of Ukraine where there are no hostilities, and the population can freely receive vaccination [37].

Given the barriers to vaccination acceptance, despite the hostilities, it is necessary to continue to carry out awareness-raising work in the media, covering not only the events of the war but also setting the population on the need to receive the first and second doses of the COVID-19 vaccine for previously unvaccinated individuals, and a booster dose for those who previously received two doses of the vaccine, involving opinion leaders in such work. It is necessary to continue to develop and implement educational programs aimed at training different groups of the population in measures to prevent COVID-19. The effectiveness of educational programs has been shown by researchers [38]. It is advisable to introduce such programs at universities, especially when training medical workers who will subsequently educate the population.

It is also necessary to inform the population about the current epidemic situation regarding COVID-19 in Ukraine - the number of cases, deaths, hospitalizations, etc., and highlight the pace of vaccination. This is necessary not only for the population of Ukraine and decision-makers but also for the public health authorities of neighboring countries, where large flows of refugees have gone.

Conclusions

The paper is devoted to a multidisciplinary study of wartime COVID-19 vaccination in Ukraine using sociological analysis, simulation modeling, and epidemiological analysis.

A sociological study of 437 donors and 797 medical workers was conducted, which identified four clusters concerning vaccination in Ukraine: supporters, loyalists, conformists, and skeptics. An ARIMA model has been developed to estimate the required vaccination coverage against COVID-19 in Ukraine. For the pilot study, we used the data on vaccination against COVID-19 in Ukraine, posted in the World Health Organization Dashboard. Verification of the model using retrospective forecasting for the period 01/25/22 - 02/23/22 showed an accuracy of 98.79 %.

The scientific novelty of the study lies in the use of sociological research and simulation to assess the required vaccination coverage against COVID-19. The proposed approach showed high accuracy for various forecasting periods. This made it possible to estimate the required vaccination coverage against COVID-19 in Ukraine during the war.

The practical novelty of the study lies in the assessment of the mandatory vaccination coverage against COVID-19 in Ukraine during wartime. The proposed tool is essential during active combat operations with limited human and computing resources. The resulting forecast will effectively make adjustments to the policies

to combat COVID-19 in Ukraine during the war.

The results of the study showed that, given the barriers to vaccination acceptance, despite the hostilities, it is necessary to continue to conduct awareness-raising work in the media, covering not only the events of the war but also setting the population on the need to receive the first and second doses of the COVID-19 vaccine for previously unvaccinated individuals, and a booster dose for those who previously received two doses of the vaccine, involving opinion leaders in such work. It is necessary to continue to develop and implement educational programs aimed at training different groups of the population in measures to prevent COVID-19. The population should also be informed about the current epidemic situation regarding COVID-19 in Ukraine - the number of cases, deaths, hospitalizations, etc., and highlight the pace of vaccination. This is necessary not only for the population of Ukraine and decision-makers but also for the public health authorities of neighboring countries, where large flows of refugees have gone.

Contributions of authors: conceptualization – **D. Chumachenko**; methodology – **D. Chumachenko**, **O. Muradyan**; formulation of tasks – **D. Chumachenko**, **I. Meniailov**, **O. Muradyan**; analysis – **D. Chumachenko**, **T. Chumachenko**, **N. Kirinovich**, **I. Meniailov**, **O. Muradyan**, **O. Salun**; cluster analysis – **O. Muradyan**; development of model – **D. Chumachenko**, **N. Kirinovich**, **I. Meniailov**; software – **N. Kirinovich**, **I. Meniailov**; verification – **D. Chumachenko**, **N. Kirinovich**; analysis of results – **D. Chumachenko**, **T. Chumachenko**, **O. Muradyan**; visualization – **N. Kirinovich**, **I. Meniailov**; writing – original draft preparation – **D. Chumachenko**, **T. Chumachenko**, **O. Muradyan**; writing – review and editing – **N. Kirinovich**, **I. Meniailov**, **O. Salun**.

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БАР'ЄРИ ВАКЦИНАЦІЇ ПРОТИ COVID-19 В УКРАЇНІ ПІД ЧАС ВІЙНИ: РЕЗУЛЬТАТИ МОДЕЛЮВАННЯ ЗА ДОПОМОГОЮ МОДЕЛІ ARIMA

Д. І. Чумаченко, Т. О. Чумаченко, Н. С. Кірінович, Є. С. Меньяйлов, О. С. Мурадян, О. О. Салун

Пандемія COVID-19 стала викликом для систем охорони здоров'я у всьому світі. Станом на червень 2022 року у світі зареєстровано понад 545 мільйонів випадків, понад 6,34 мільйони з яких померли. Безпричинна

та кровопролитна війна, розв'язана Росією в Україні, торкнулася системи охорони здоров'я, у тому числі порушила плани вакцинації від COVID-19. Використання імітаційних моделей для оцінки необхідного охоплення вакцинацією проти COVID-19 в Україні дозволить оперативно вносити зміни до політики боротьби з пандемією у воєнний час. **Метою дослідження** є розробка моделі вакцинації проти COVID-19 в Україні та дослідження впливу війни на цей процес. Дослідження є мультидисциплінарним і включає соціологічне вивчення ставлення населення України до вакцинації проти COVID-19 до ескалації війни, моделювання вакцинальної кампанії та прогнозування необхідної кількості доз, що вводяться після початку війни, епідеміологічний аналіз результатів моделювання. **Об'єкт дослідження** – епідемічний процес COVID-19 під час війни. **Предмет дослідження** – моделі та методи моделювання епідемічного процесу на основі статистичного машинного навчання. Для досягнення мети було застосовано **методи** соціологічного аналізу та побудовано модель ARIMA для оцінки охоплення вакцинацією проти COVID-19. В **результаті** дослідження населення України було кластеризовано по відношенню до вакцинації проти COVID-19. В результаті соціологічного дослідження 437 донорів та 797 медичних працівників було виділено чотири класи: прихильники, лоялісти, конформісти та скептики. Модель ARIMA була побудована для моделювання щоденного охоплення щепленнями проти COVID-19. Ретроспективний прогноз підтвердив точність моделі на період з 25.01.22 по 23.02.22 в Україні. Точність прогнозу на 30 днів становить 98,79%. Модель застосовувалася з метою оцінки необхідного охоплення вакцинацією в Україні на період 24.02.22 – 25.03.22. **Висновки.** Мультидисциплінарне дослідження дозволило оцінити прихильність населення України до вакцинації проти COVID-19 та розробити модель ARIMA для оцінки необхідного охоплення вакцинацією проти COVID-19 в Україні. Розроблена модель показала високу точність і може використовуватися установами громадської охорони здоров'я для коригування політики вакцинації у воєнний час. Враховуючи бар'єри на шляху прийняття вакцинації, незважаючи на бойові дії, необхідно продовжувати проводити просвітницьку роботу в ЗМІ, висвітлюючи не лише події війни, але й налаштовуючи населення на необхідність отримання першої та другої доз вакцини проти COVID-19 для людей, які раніше не були щеплені, і ревакцинації для тих, хто раніше отримав дві дози вакцини, із залученням до такої роботи лідерів громадської думки.

Ключові слова: епідемічна модель; епідемічний процес; моделювання епідемії; моделювання; COVID-19; ARIMA, війна.

Чумаченко Дмитро Ігорович – канд. техн. наук, доц., доц. каф. математичного моделювання та штучного інтелекту, Національний аерокосмічний університет ім. М. Є. Жуковського «Харківський авіаційний інститут», Харків, Україна.

Чумаченко Тетяна Олександрівна – д-р мед. наук, проф., зав. каф. епідеміології, Харківський національний медичний університет, Харків, Україна.

Кірінович Наталія Сергіївна – здобувач каф. математичного моделювання та штучного інтелекту, Національний аерокосмічний університет ім. М. Є. Жуковського «Харківський авіаційний інститут», Харків, Україна.

Меняйлов Євген Сергійович – канд. техн. наук, в.о. зав. каф. теоретичної та прикладної інформатики, Харківський національний університет ім. В. Н. Каразіна, Харків, Україна.

Мурадян Олена Сергіївна – канд. соціол. наук, доц., декан соціологічного факультету, Харківський національний університет ім. В. Н. Каразіна, Харків, Україна.

Салун Ольга Олександрівна – здобувач каф. епідеміології, Харківський національний медичний університет, Харків, Україна.

Dmytro Chumachenko – PhD in Artificial Intelligence, Associate Professor, Associate Professor of Department of Mathematical Modelling and Artificial Intelligence, National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine, e-mail: dichumachenko@gmail.com, ORCID: 0000-0003-2623-3294.

Tetyana Chumachenko – Doctor of Medical Sciences, Professor, Head of Department of Epidemiology, Kharkiv National Medical University, Kharkiv, Ukraine, e-mail: tatalchum@gmail.com, ORCID: 0000-0002-4175-2941.

Nataliia Kirinovich – applicant of Department of Mathematical Modelling and Artificial Intelligence, National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine, e-mail: kirinovich.natasha@gmail.com, ORCID: 0000-0002-8426-9992.

Ievgen Meniailov – PhD in Mathematical Modelling and Optimization Methods, Acting Head of Theoretical and Applied Informatics, V. N. Karazin Kharkiv National University, Kharkiv, Ukraine, e-mail: evgenii.meniailov@gmail.com, ORCID: 0000-0002-9440-8378.

Olena Muradyan – PhD in Sociology, Associate Professor, Dean of Faculty of Sociology, V. N. Karazin Kharkiv National University, Kharkiv, Ukraine, e-mail: o.s.muradyan@karazin.ua, ORCID: 0000-0003-0990-9635.

Olga Salun – applicant of Department of Epidemiology, Kharkiv National Medical University, Kharkiv, Ukraine, e-mail: olga.salun87@gmail.com, ORCID: 0000-0002-4399-1030.