Ministry of Education and Science of Ukraine
Sumy State University
Education and Research Institute of Business, Economics, and Management
Economic Cybernetics Department

BACHELOR'S QUALIFICATION WORK

on the topic «FORECASTING THE DYNAMICS OF COVID-19 IN UKRAINE BASED ON HARMONIC ANALYSIS»

Completed a 4th year student, group AB-71-8a,

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Sumy – 2021

ABSTRACT

qualifying work on the topic
«FORECASTING THE DYNAMICS OF COVID-19 IN UKRAINE BASED ON HARMONIC ANALYSIS»

Student Marchenko Roman Vladimirovich

The relevance of this study is that since the pandemic situation in Ukraine revealed insufficient readiness of the health care system to respond quickly to crises, the low financial security of most municipal primary and secondary care, which was reflected at least in low material support and more. The crisis has revealed many problems in the medical field that have long existed at the global, state, regional, and local levels. Today, it is necessary to conduct a detailed analysis of the population's health, the state of the resource and technological support of medical institutions, availability (physical, financial), and quality of medical care at all levels to more effectively deal with possible epidemiological disasters.

Another essential element in assessing the situation in the health sector is the lack or underdevelopment of scientific and methodological approaches to identify critical areas for new strategic action. To this end, it is essential to conduct in-depth and detailed statistical studies to identify patterns that will be the basis for further forecasting the state of regional health care systems and other decisions on resource provision.

The purpose of the qualification work: to develop an economic and mathematical model for predicting the level of morbidity to COVID-19 (on the example of Ukraine) for the timely detection and prevention of epidemiological threats.

The object of research: the incidence of COVID-19 in Ukraine.

The subject of research: predicting the incidence of COVID-19.

The objectives of the study are:

1. Analysis of the current state of research on pandemics, the search for causal links between the transformation of different industries and the coronavirus.
2. Study of the existing methodical bases of forecasting of epidemiological waves.
3. Analysis of relevant statistics for further modeling and forecasting.
4. Development of a model based on harmonic analysis.
5. Construction of forecasts and summarizing according to the received data..

To achieve the goal and objectives of the study, the following research methods were used: generalized systematization of knowledge studied during the study of economic processes; financial and economic analysis, graphic and statistical methods of grouping the received information; method of analysis and synthesis of acquired knowledge; generalization of the received information; correlation-regression analysis; harmonic analysis.

The information base of qualification work is: monographs, scientific researches, scientific articles, textbooks.

The obtained results can be used by students of economic faculties, scientists, enterprises and organizations of all forms of ownership in the analysis of the impact of Covid-19.

Keywords: Forecasting, time series, simulation, economics, virus, Covid-19, Fourier, statistics, morbidity, mortality, Python, MathCad, API

The content of the qualification work is presented on _37_ pages. List of used sources from _40_ names. The work contains _1_ tables, _16_ figures, and _1_ appendices.

Year of qualification work - 2021.

Year of work protection - 2021.

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“__” ____________2021 year

TASKS

FOR THE BACHELOR'S QUALIFICATION WORK
Student ___4_____ course Group __AB-71-8a____
course number group code

Marchenko Roman Vladimirovich
(first name, surname)

1. Theme of work *«Forecasting the dynamics of COVID-19 in Ukraine based on harmonic analysis»,* approved by the order of the University of "15" March 2021 № 0383-III.
2. The deadline for students to submit the completed work "18" is June 2021.
3. The purpose of the qualification work: to develop an economic and mathematical model for predicting the level of morbidity to COVID-19 (on the example of Ukraine) for timely detection and prevention of epidemiological threats.
4. Object of research: the incidence of COVID-19 in Ukraine.
5. Subject of research: predicting the incidence of COVID-19.
6. Qualification work is performed on materials ____
7. Indicative plan of qualification work, terms of submission of sections to the head and the maintenance of tasks for performance of the set purpose

Section 1 The role of forecasting the level of epidemiological vulnerability. June 4.

In section 1 to reveal the essence of the concept of vulnerability to the effects of a pandemic; to analyze the existing approaches and methods devoted to the consequences of the pandemic, to identify the shortcomings of the existing ones and to determine the place of the task of forecasting the dynamics of COVID-19 development; consider existing methods and models for predicting vulnerabilities from COVID-19.

Section 2. Forecasting based on harmonic analysis. June 11

In section 2 to check the stationarity and periodicity of the studied indicator, to develop an economic-mathematical model for predicting the incidence rate, by constructing Fourier series, to check the adequacy of the model, to develop recommendations in accordance with the forecast.

8. Consultations on work:

Section	Surname, initials and position of the consultant	Signature, date	
		task issued	task accepted
1	Kuzmenko O.V.		
2	Kuzmenko O.V.		
3	Kuzmenko O.V.		

9. The date of issuance of the task "01" is March 2021.

Head of qualification work _________ Kuzmenko O.V.
Tasks to perform received _________ Marchenko R.V.

CONTENT

INTRODUCTION

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Another essential element in assessing the situation in the health sector is the lack or underdevelopment of scientific and methodological approaches to identify critical areas for new strategic action. To this end, it is essential to conduct in-depth and detailed statistical studies to identify patterns that will be the basis for further forecasting the state of regional health care systems and other decisions on resource provision.

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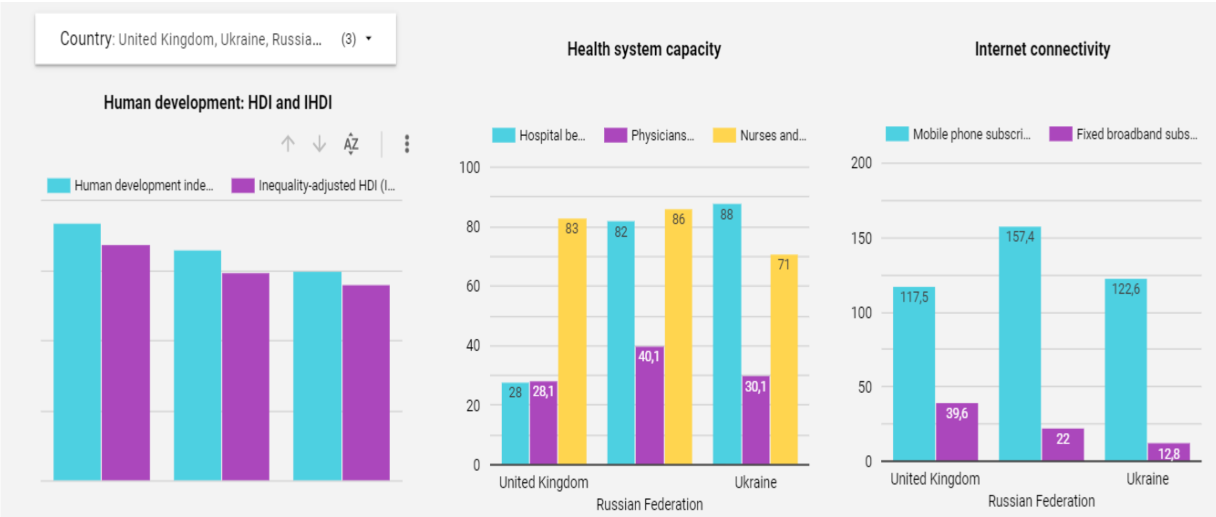
SECTION 1. THE ROLE OF FORECASTING THE LEVEL OF EPIDEMIOLOGICAL VULNERABILITY.

1.1. The essence of the concept of "vulnerability" of the region

The COVID-19 crisis is more than a global health emergency that has an unprecedented impact on life's economic, political, and social spheres.

Every society, group, and individual is vulnerable to adverse events. However, when it comes to disasters such as the COVID-19 pandemic, our ability to respond and adapt is much lower and unevenly distributed than an everyday and quiet life.

The data visualization and information panel (img.1.1) below several present indicators for human development groups, regions, and countries (United Kingdom, Russian Federation, Ukraine), which show the level of readiness to respond and cope with the consequences of the COVID-19 crisis, including the story of human development, health system capacity and Internet access.



Img.1.1 - PREPAREDNESS OF COUNTRIES TO RESPOND TO COVID

Source: [1]

As we can see, the level of human development in Ukraine is lower than in the United Kingdom and the Russian Federation. In terms of the capacity of the health care system, the domestic system is estimated to be at an average level compared to the countries with which it is compared. Internet access, which has forcibly become the lifestyle of many, is also low compared to these countries. The level of human development and its inequality, and the capacity of the health care system can show the readiness of countries to respond effectively to the health care crisis. For example, a country with a very high level of human development has an average of 55 hospital beds, more than 30 doctors, and 81 nurses per 10,000 people, compared to 7 hospital beds, 2.5 doctors, and six nurses in the least developed country. Widespread blocking worldwide means that many people have to rely on Internet access to work, continue their education, and interact with others. The digital divide has grown as never before, as hundreds of millions of people worldwide still do not have access to reliable broadband Internet.

Human Development Groups	Human development index (HDI) (value), 2018	Inequality-adjusted HDI (IHDI) (value), 2018	Inequality in HDI (percent), 2018	Physicians (per 10,000 people), 2010-17	Nurses and midwifes (per 10,000 people), 2010-18	Hospital beds (per 10,000 people), 2010-18	Current health expenditure (% of GDP), 2016	Mobile phone subscription (per 100 people), 2017-18	Fixed broadband subscriptions (per 100 people), 2017-18
Very high human development	0,892	0,796	10,8	30,4	81	55	12,0	127,8	30,5
High human development	0,750	0,615	17,9	16,5	30	32	5,7	113,6	18,8
Medium human development	0,634	0,507	20,0	7,3	17	9	3,9	91,9	2,4
Low human development	0,507	0,349	31,1	2,1	8	6	4,5	67,5	0,4

Regions	Human development index (HDI) (value), 2018	Inequality-adjusted HDI (IHDI) (value), 2018	Inequality in HDI (percent), 2018	Physicians (per 10,000 people), 2010-17	Nurses and midwifes (per 10,000 people), 2010-18	Hospital beds (per 10,000 people), 2010-18	Current health expenditure (% of GDP), 2016	Mobile phone subscription (per 100 people), 2017-18	Fixed broadband subscriptions (per 100 people), 2017-18
Developing countries	0,686	0,547	20,3	11,5	23	21	5,3	99,2	10,2
Arab States	0,703	0,531	24,5	11,1	21	15	4,9	100,3	7,4
East Asia and the Pacific	0,741	0,618	16,6	14,8	22	35	4,8	117,6	21,3
Europe and Central Asia	0,779	0,689	11,5	24,9	61	51	5,2	107,3	14,6
Latin America and the Caribbean	0,759	0,589	22,4	21,6	47	20	8,0	103,6	12,8
South Asia	0,642	0,520	19,0	7,8	17	8	4,1	87,7	2,2
Sub-Saharan Africa	0,541	0,376	30,5	2,1	10	8	5,3	76,9	0,4
Least developed countries	0,528	0,377	28,6	2,5	6	7	4,2	70,9	1,4
Small Island developing states	0,723	0,549	24,0	22,2	28	25	5,9	80,5	6,4
Organisation for Economic Co-operation and Development	0,895	0,790	11,7	28,9	80	50	12,6	119,3	31,6
World	0,731	0,596	18,6	14,9	34	28	9,8	104	14

Img. 1.2 –Group and Regions respond to COVID -19

Source: [1]

On Img. 1.2 It is possible to monitor the preparedness of countries to respond to the crisis caused by the COVID-19 pandemic and the level of their vulnerability. Although this pandemic affects everyone in one way or another, some people and groups are more vulnerable, suffer much more damage, and have a much longer path to recovery.

Img.-1.3 presents indicators for human development groups that reflect human vulnerability, including poverty, social protection, labor programs, and the propensity of the economy for the immediate economic consequences of travel bans. Poverty increases the risk of long-term consequences. Despite recent progress in reducing poverty, about one in four people still live in or are vulnerable to multidimensional poverty. More than 40 percent of the world's population has no social protection.

Regions	Population in multidimensional poverty (%), 2009-18	Population vulnerable to multidimensional poverty (%), 2009-18	PPP $ 1.90 a day (%), 2010-18	National poverty line (%), 2010-18	Working poor at PPP $ 3.20 a day (% of total employment), 2018	Social protection and labour programs (% of population without any), 2007-2016	Remittances, inflows (% of GDP), 2018	Net official development assistance received (% of GNI) 2017	Inbound tourism expenditure (percent of GDP), 2016-18
Developing countries	23,1	15,3	12,6	19,3	25,9	43	1,5	0,3	1,8
Arab States	15,7	9,4	4,7	23,0	14,9	52,8	2,7	1,7	3,6
East Asia and the Pacific	5,6	14,9	1,5	5,1	10,1	41,7	0,6	0,0	1,4
Europe and Central Asia	1,1	3,6	-	11,5	9,2	42,6	2,8	0,7	4,2
Latin America and the Caribbean	7,3	7,5	3,8	-	6,8	40,6	1,6	0,1	1,6
South Asia	31,0	18,8	17,4	22,9	43	25,1	3,4	0,4	1
Sub-Saharan Africa	57,5	17,2	43,5	43,0	63,1	79,4	2,9	2,8	2
Least developed countries	59,0	17,8	36,7	38,1	59,7	84,5	4,6	4,9	2,4
Small Island Developing States	22,6	12,9	-	-	17,7	75,3	6,9	1,5	8,3
Organisation for Economic Co-operation and Development	-	-	0,7	-	-	36	0,3	-	2,1

Img.1.3 - VULNERABILITY TO PANDEMICS

Source: [2]

Globalization has brought new opportunities and increased efficiencies, but as the COVID-19 pandemic shows, failures at one point in the chain can cause severe local problems elsewhere. Such events can be detrimental to countries and people who are heavily dependent on tourism, such as island nations, remittances, or official development assistance.

1.2. An overview of the current state of research on issues related to the COVID-19 pandemic

The scientific community of the world has paid much attention to COVID-19. Researchers are looking for ways to overcome the adverse effects of the pandemic that have led to the transformation of the world economy, medicine, the state of the environment, education, and so on. Other authors look for causal links between differentiated vulnerabilities of different countries or regions within one state and the state of other areas of society, such as social, environmental, economic. A large number of scientists have conducted a cluster analysis to divide all countries into vulnerability groups to the effects of a pandemic.

An analysis of the modern scientific literature has shown that scientists worldwide have changed the direction of their interests in the context of the pandemic. The dispersion of COVID-19 interests is very significant in any area affected by the pandemic: medicine and pharmaceuticals, primarily to combat the disease itself. The global economic crisis is forcing economists worldwide to focus on estimating the magnitude of losses, possible options for leveling the adverse effects and finding cause-and-effect relationships of differentiated effects. Special attention of world scientists is focused on forecasting future conditions for timely prevention.

The study [3] was conducted at the beginning of the pandemic in April 2020. Even then, the analysis of publications for ten weeks showed rapid growth of news on pandemic issues. The spread of COVID-19 worldwide has dramatically changed the direction of the vector of interest of many researchers around the world. For example, [4] emphasizes that the world economy has undergone significant changes due to the pandemic and will not return to its previous state. The authors cite several possible economic and political development scenarios for the world and especially for their country.

The authors [5] reflect in detail the mistakes made by governments worldwide in the fight against the virus in terms of political economy. It is emphasized that at the very beginning of the epidemic, decision-makers at the national level did not fully realize the looming threat and did not bring to justice the responsibility of those who had already become infected to the rest of society.

In [6], the authors propose four alternative scenarios in the long run that will help restore the world economy, eliminate obstacles to stable economic growth, "green" economic recovery, or reconstruction. Emphasize that, given the challenges of COVID-19, it is necessary to prioritize between the rapid development of products or environmental issues, between the level of implementation of the state or the market.

Scientists [7] consider the economic consequences of a pandemic on the example of Italy, which has the tools to mitigate the adverse effects of economic crises, provided they expect and conclude that no country's economy can cope with the effects alone, only through coordinated action. In [8], the current state of the economy is considered to be emerging from the pandemic crisis, and new business solutions are emerging in the world. Business solutions are given in the long run. The latest technologies, especially those related to remote implementation or cloud technologies, are closely rooted in modern life due to quarantine restrictions. The pandemic set difficult conditions for business, but at the same time, acted as a catalyst for the implementation of new business ideas, which a few years ago were considered fantastic.

Research [9] focuses public attention on increasing the burden on the care economy, which is primarily domestic and unpaid worldwide. Due to quarantine restrictions worldwide, many workers switched to distance work, children to homeschooling, which increased the workload of both physical and mental work. The authors insist on reviewing and considering changes in the distribution of social protection of such segments of the population. In [10], the authors focused on many modern scientific papers on the consequences of the pandemic in terms of the economy. They systematized the literature on various areas of social, environmental, discrimination and employment in quarantine.

Work [11] looks at the healthcare recession as it is the first to change. Despite increasing subsidies to the medical industry worldwide, they focus on overcoming the SARS-CoV-2 virus, but the gaps that have primary and secondary links are now almost unresolved. In our opinion, it is successful to compare hospitals with the service sector in the sense that, for example, chronic diseases do not disappear during a pandemic but are only postponed, unlike the service sector, which will never get lost customers. The study [12] also focuses on the fact that the Covid-19 pandemic is primarily a medical crisis. Any economic crisis has resulted in deteriorating public health, but now the situation is the opposite. Revaluation of values is the most significant consequence of the pandemic under study. The medical and social spheres have been underestimated for a very long time, resulting from which we have had an explosion of negative consequences around the world. The authors provide real examples of reassessing the priorities of society's development after economic crises and set the tent to focus on health, social protection, and the environment throughout the civilized world.

The authors [13] focus their research on finding the best option for everyday life during a pandemic, where the emphasis is on reducing the social activity of citizens, and as a result - staying at home and reducing economic activity, on the other - the need to provide activities, so that the economic crisis does not increase even more. Two strategies of social activity are proposed, such as dividing society into groups depending on the time of day, and the other - restrictions on people being in one place at the same time. Scientists emphasize that only following both strategies can achieve the most significant effect in combating the virus.

Scientists [14] have empirically proven the negative impact of quarantine restrictions on economic activity in stock markets. In addition to the most mentioned distancing of citizens, they see the reason in the instability of shares, as a result of which most investors have transferred their assets to the most stable projects, thus transforming the global stock market.

In work [15], a course of events for current and possible future pandemics is proposed. Researchers suggest not to stop the economy, not to impose quarantine restrictions, but to focus on developing the medical field. By increasing the number of medical beds per million population, developing a policy of isolation of the infected even during the incubation period, it is possible, according to the authors, to achieve a good result in the fight against the virus itself. The results are also presented that with increasing the load on the medical sphere, full and partial quarantine has the same effect, which leads to reflections on the feasibility of introducing a complete lockdown. Also, in the study [16], the authors look for relationships between the number of days under which quarantine restrictions applied, the strength of the restrictions, and the dynamics of the spread of the disease in 49 countries. The result is that isolation can slow down the spread of the virus. In addition, the lockdown has a positive effect on the environment and has good results in psychological terms. As we can see, these two studies have the opposite result, which leads us to conclude that there are several tools for epidemiological crises, each of which has both advantages and disadvantages.

Scientific work [17] emphasizes the development of general rules for the whole world that will help keep the spread of the virus under control. In addition, the development of a typical practical scenario will help in the fight against other respiratory diseases, which will automatically reduce the burden on the medical sector and reduce government spending in this area. Researchers [18] on the example of the Persian Gulf countries have demonstrated the effects of a pandemic. The logical chain is as follows: curfew, bans on entry and exit have led to the fact that a large number of projects in these countries have already faced a shortage of human resources, materials, which led to a shutdown and may not be fully restored shortly time.

Scientists [19] have thoroughly analyzed the dependence of employee motivation during a pandemic on work efficiency. This issue becomes especially acute during the transition of most businesses, where possible, to the small sphere. If in the past remote work was an advantage, now the priorities have changed dramatically. A survey conducted by researchers shows differentiated views on motivation on the part of employees and employers. In [20], readers' attention is focused on the fact that during the transformation of the world due to quarantine restrictions, priorities in various spheres of social change and its digitalization come to the fore. A detailed analysis of the latest technologies, in particular blockchain technologies, has been developed. Artificial intelligence methods are designed to help humanity in changing times and eliminate uncertainty in many areas.

Researchers [21] theoretically substantiated that the pandemic hurt the green investment market, and it was a reaction to the increase in mortality. [22] links the work of insurance companies and the consequences of Covid-19, despite the emergence of new insurance policies directly related to the pandemic, yet the remote work of agents is not as effective as personal contact with the client.

1.3. Review of the current state of disease prediction from COVID-19.

A special place in modern research on pandemics is given to forecasting future conditions. No one could have predicted the appearance of such a virus, which transforms the whole world. However, today, many scientists aim to help governments prepare in advance for new, possible waves.

For example, researchers [23] analyzed and predicted the spread of the disease in Italy, France, and China, using the SIR (Susceptible - Infected - Recovered) model, recursive relationships, and nonlinear approximation. This model is adapted to study the epidemiological status of the disease in the region, for which the entire population is divided into three groups:

1) Vulnerable to the disease;
2) Infected;
3) Already recovered.

A modification of this model is the SEIR model (Susceptible - Exposed - Infected - Recovered). The population is divided into four groups: a group is added - those in the incubation period. Analyzing the dynamics of changes in the ratio of each of the groups, it is possible to conclude the feasibility of introducing additional social restrictions. The disadvantage of this method is that it does not demonstrate different development scenarios, so it is not independent but works effectively only in conjunction with others.

The study [24] aimed to predict the incidence and mortality of COVID-19 based on several models, such as using the autoregressive moving average ARIMA and the Holt-Winters additive model. The ARIMA model is designed to take into account local changes by removing white noise from the time series using a linear correlation between the levels of the series. The model is quite applicable because it is easy to interpret. It is quite simple to update the results, which, incidentally, are pretty accurate. However, because this model uses only linear dependences, the study of complex systems (study of the effects of a pandemic considers the multifactorial and complexity of the system) approximation of its results does not always work. The Holt-Winters additive model uses exponential smoothing, taking into account additive seasonality and trend. The term exponential smoothing means a revaluation of the forecast, with more weight taking into account the new data, compared with the previous ones, due to the weights. When constructing a forecast, the newer the observation, the greater its weight for future conditions. The obligatory stage of this modeling is to check the anomalous emissions for regularities. Among the disadvantages of this forecasting model are entirely inaccurate results.

Also, in work [25], the result obtained using the TVAT model (T - trigonometric transformation, B - Boxing transformation, A - ARIMA error, T -

trend) is given. This model uses a trigonometric component to study seasonality, taking into account trends and normalization. This model is empirically tested and gives entirely accurate results due to the decomposition of seasonal time series. Also, this model allows you to identify those seasonal components that are not visible on the chart. Among its disadvantages is the complexity of the application. Especially for data updates, it is necessary to carry out the whole procedure first.

One of the forecasting methods is the Prophet model (developed for Facebook), which is described in detail in [26]. The scope of this model is business. This is a disadvantage of this model, but many business solutions have features similar to many other industries that require forecasting. For most of its components, this model is regressive but partly relies on the Fourier series, in which the parameters are easy to interpret, consists of two parts:

1) A model of saturated growth that corresponds to models of population growth with elements of nonlinearity. To build a forecast, the saturation point is never reached.

2) A piecewise linear model that is easy to adjust to new circumstances, but it does not work well enough with default values.

Scientific research [27] uses probabilistic prediction of DeepAR, which is used based on recursive neural networks of both short-term and long-term memory. The greater the depth of the network, the more accurate the result. Among the advantages of this method is the result obtained in the number of the spectrum of probabilistic predictions based on the Monte Carlo method. The model can also work with minimal manual intervention.

Table 1.1 - Generalized characteristics of approaches to predicting the incidence of COVID-19

The name of the approach	Benefits	Disadvantages
SIR (or SEIR) simulation model	Simple, taking into account the specifics - predicting the dynamics of infectious diseases	It does not allow to see different development scenarios. Effective in combination with other forecasting methods.

ARIMA	Accurate, easy to update, easy to interpret results	Only linear relationships are used
Holt-Winters additive model	Simplicity, taking into account the importance of recent observations over older ones	Not high accuracy
TVAT	Quite an accurate result	It is difficult to update to new data.
Prophet	Easily updated	Complexity of implementation, business-oriented.
DeepAR	Large range of probabilistic predictions based on the Monte Carlo method.	Disadvantages

A generalized description of the above methods is presented in table 1.1. The issue of forecasting is one of the most exciting and problematic among modern scientists. This is confirmed by a wide range of methods that have their disadvantages and advantages. When forecasting the future incidence of COVID-19, it is essential to consider the specifics of the industry, trend, and seasonality. Many methods are based on the Fourier series, a probabilistic component that is implemented using the Monte Carlo method or neural networks. After analyzing the above methods, we decided to use harmonic analysis in our study based on the transformation of the time series into a Fourier series.

SECTION 2. PREDICTION OF COVID-19 MORBIDITY OF THE POPULATION OF UKRAINE ON THE BASIS OF HARMONIC ANALYSIS

2.1 Selection of static data

To model and predict the phenomena associated with any epidemiological situation, it is necessary to consider such indicators as the total number of infected and the number of deaths per unit time. These two factors, mortality, and morbidity are interrelated, as the number of people who become ill will affect the number of deaths caused by the disease, and vice versa. The problem with mortality is that these data are not always objective. For example, it is debatable whether a person died from complications caused by the disease or vice versa - was treated for another, such as a chronic disease and added to the diagnosis of Covid-19 - in which case it is more appropriate to include in the statistics of deaths from Covid-19, whether in both cases. Therefore, for further research, we will choose the indicator: the number of infected. However, if necessary, the methodology demonstrated below can be carried out for: "the number of people who died from Covid-19".

Let us form a dataset which we will investigate. Take the data from a network of public APIs [28] using the high-level Python general-purpose programming language [29], the Requests library [30], which allows sending HTTP requests [31], and the Pandas data analysis library [32], which is shown in Img. 2.1.

```
import requests
import json
import pandas as pd

url_ua= "https://api.covid19api.com/total/country/ukraine"  #connect API
df = pd.read_json(url_ua) #read JSON
```

Img 2.1 – create DataFrame

We request the link https://api.covid19api.com/total/country/ukraine from which we obtain data in JSON format [33] and convert it for better perception in Pandas Dataframe [34]. All operations are performed in the Jupyter Notebook [35]. Take all the historical data on the development of Covid-19 in Ukraine. A fragment of these data is shown in Img. 2.2. and analyze them. We will receive 12 columns and 492 rows, each of which corresponds to one day, i.e., these data are daily even for the first registered patient in Ukraine and until May 2, 2021.

```
data = df.copy()
data.head # show data
```

```
<bound method NDFrame.head of      Country CountryCode Province  ... Recovered  Active
0    Ukraine                        ...         0       0 2020-01-22 00:00:00+00:00
1    Ukraine                        ...         0       0 2020-01-23 00:00:00+00:00
2    Ukraine                        ...         0       0 2020-01-24 00:00:00+00:00
3    Ukraine                        ...         0       0 2020-01-25 00:00:00+00:00
4    Ukraine                        ...         0       0 2020-01-26 00:00:00+00:00
..       ...         ...      ...   ...       ...     ...                       ...
487  Ukraine                        ...   2003916  184628 2021-05-23 00:00:00+00:00
488  Ukraine                        ...   2010931  178998 2021-05-24 00:00:00+00:00
489  Ukraine                        ...   2028598  163804 2021-05-25 00:00:00+00:00
490  Ukraine                        ...   2043720  151987 2021-05-26 00:00:00+00:00
491  Ukraine                        ...   2060753  138401 2021-05-27 00:00:00+00:00

[492 rows x 12 columns]>
```

Img 2.2 -Show DataFrame

For further analysis, we will use only the columns 'Country', 'Confirmed', 'Deaths', 'Recovered', 'Active', 'Date', and get rid of unnecessary using the drop method [32] from the Pandas library, received the input table for further modeling, which is shown in Img. 2.3.

```
columns = ['CountryCode', 'Province', 'City', 'CityCode', 'Lat', 'Lon']
data.drop(columns, inplace=True, axis=1)
```

```
print(data)
```

```
     Country  Confirmed  Deaths  Recovered  Active                      Date
0    Ukraine          0       0          0       0 2020-01-22 00:00:00+00:00
1    Ukraine          0       0          0       0 2020-01-23 00:00:00+00:00
2    Ukraine          0       0          0       0 2020-01-24 00:00:00+00:00
3    Ukraine          0       0          0       0 2020-01-25 00:00:00+00:00
4    Ukraine          0       0          0       0 2020-01-26 00:00:00+00:00
..       ...        ...     ...        ...     ...                       ...
487  Ukraine    2239897   51353    2003916  184628 2021-05-23 00:00:00+00:00
488  Ukraine    2241354   51425    2010931  178998 2021-05-24 00:00:00+00:00
489  Ukraine    2244084   51682    2028598  163804 2021-05-25 00:00:00+00:00
490  Ukraine    2247605   51898    2043720  151987 2021-05-26 00:00:00+00:00
491  Ukraine    2251242   52088    2060753  138401 2021-05-27 00:00:00+00:00

[492 rows x 6 columns]
```

Img. 2.3 – Drop columns

These data contain accumulated indicators that are not rational to predict. Therefore, let's create new columns 'Conf_Diff', 'Deaths_Diff', 'month', 'quarter' for further analysis. In 'Conf_Diff', we will put data in which the difference on new diseases will be displayed in 'Deaths_Diff' similarly to 'Conf_Diff' but only a difference in new lethal cases absolute chain gain (1).

$$\Delta y = y_n - y_{n-1} \qquad (2.1)$$

The columns 'month' and 'quarter' will display the time period to which month or quarter it belongs, Img 2.4.

```
data['Conf_Diff'] = df.Confirmed.diff() #Get difference between two items from Confirmed list
data['Deaths_Diff'] = df.Deaths.diff() #Get difference between two items from Deaths list
data['month'] = data['Date'].dt.month # group data by month
data['quarter'] = data['Date'].dt.quarter #group data by quarter
print(data)
```

```
    Country  Confirmed  Deaths  ...  Deaths_Diff  month quarter
0   Ukraine          0       0  ...          NaN      1       1
1   Ukraine          0       0  ...          0.0      1       1
2   Ukraine          0       0  ...          0.0      1       1
3   Ukraine          0       0  ...          0.0      1       1
4   Ukraine          0       0  ...          0.0      1       1
..      ...        ...     ...  ...          ...    ...     ...
487 Ukraine    2239897   51353  ...         93.0      5       2
488 Ukraine    2241354   51425  ...         72.0      5       2
489 Ukraine    2244084   51682  ...        257.0      5       2
490 Ukraine    2247605   51898  ...        216.0      5       2
491 Ukraine    2251242   52088  ...        190.0      5       2

[492 rows x 10 columns]
```

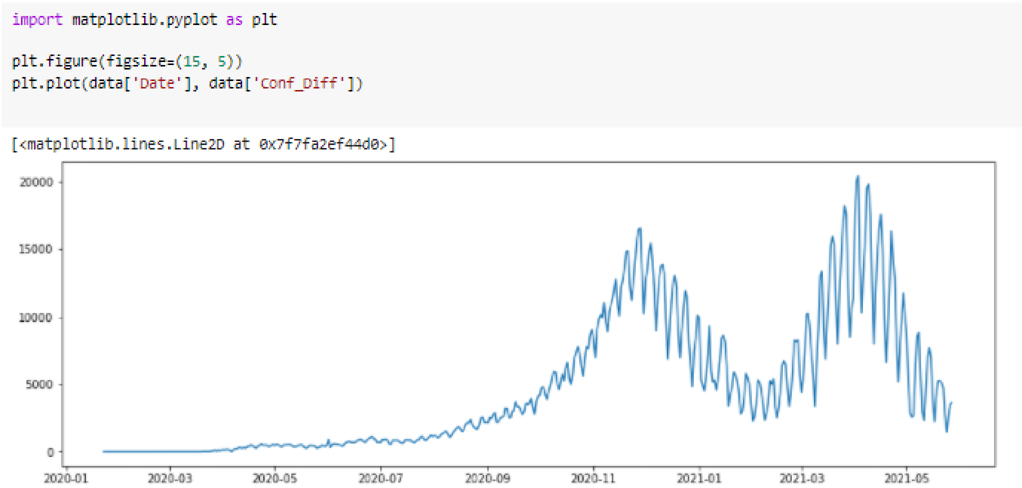
Img. 2.4 – Difference

Therefore, for further modeling, time series were obtained, consisting of absolute increments of each level of the series for the number of patients and deaths from Covid-19. For further calculations, we take the indicator "the number of new cases of Covid-19 per day" from January 22, 2020, to May 2, 2021.

2.2 Data visualization

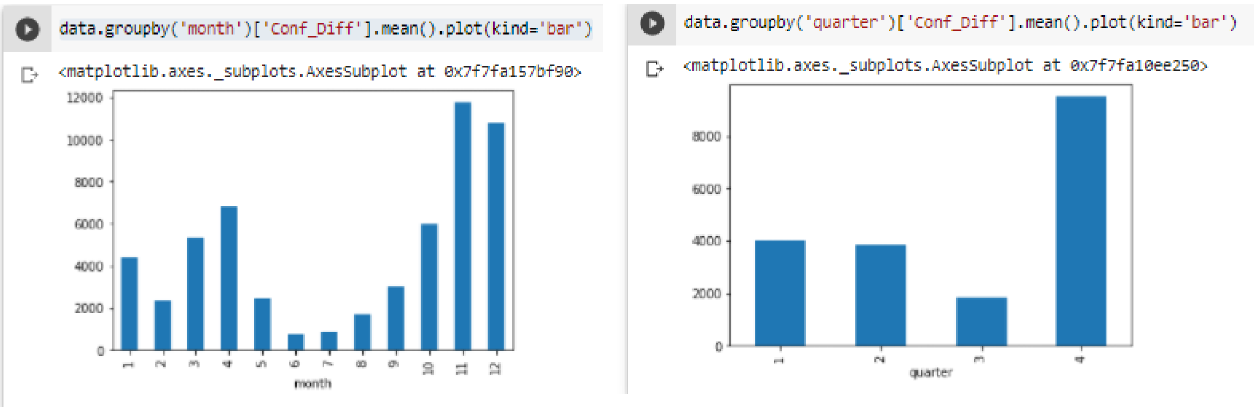
To display the graph in the Python programming language, use the Matplotlib library [36]

We follow the dynamics of the virus in Ukraine:



Img. 2.5 - Dynamics of Confirmed

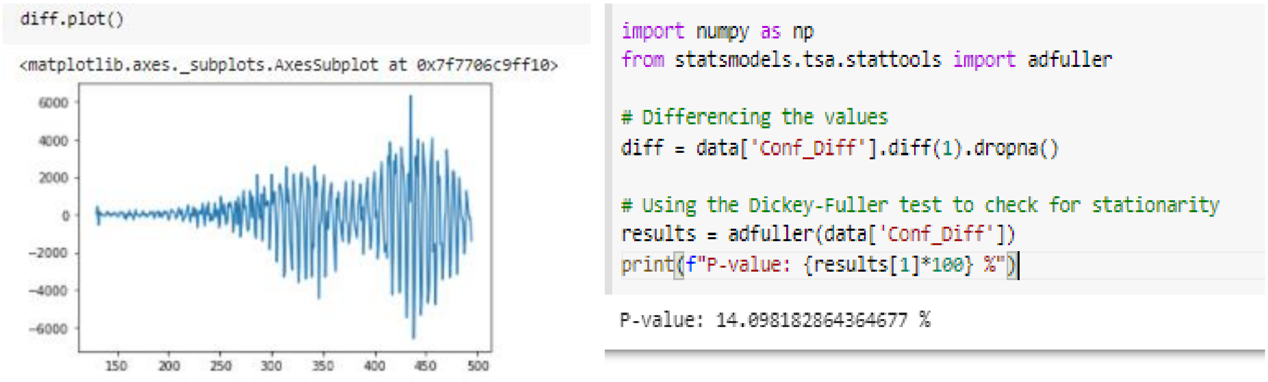
Img. 2.6 shows the average distribution of the number of patients by months and quarters, which clearly shows that the peak of the disease is concentrated in the winter.



Img. 2.6 Average over time

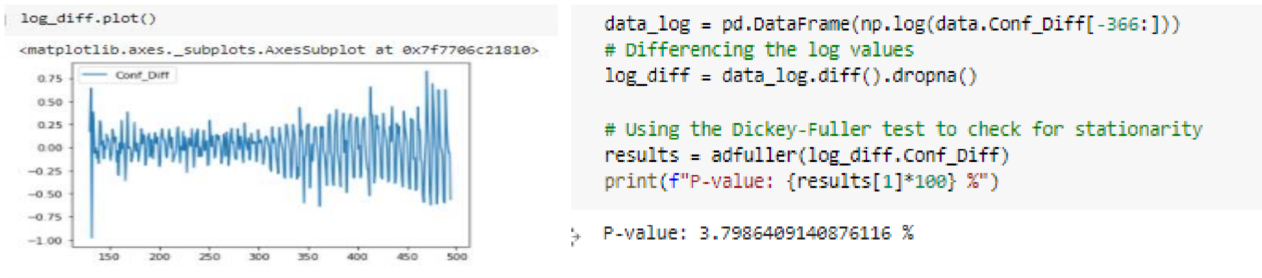
2.3 Stationarity and periodicity

Before building the model, let us check the series for stationarity and periodicity. To test for stationarity, we will use the Dickey-Fuller test [37]. The Statsmodels module for Python has an adfuller () function. [38], the result of which is shown in Img. 2.7



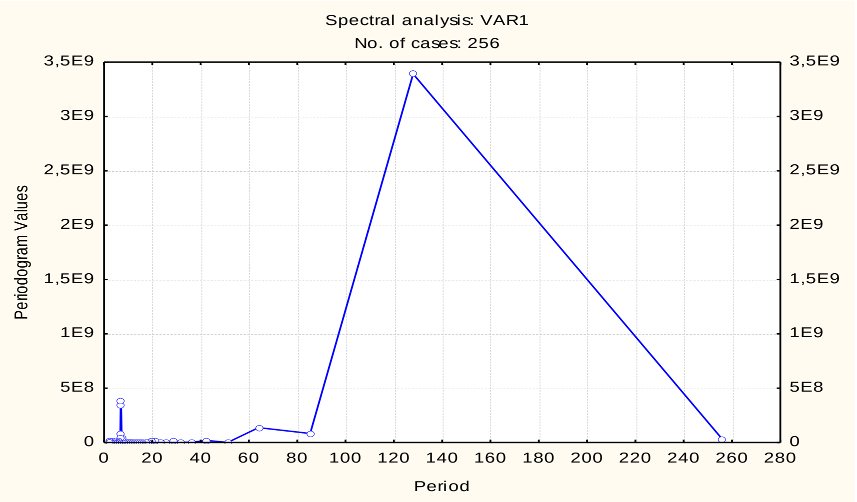
Img. 2.7 – Dickey-Fuller test

The value of P = 14%, which is more than 5% - we conclude that our time series is not stationary. Prologarithmize the data (Img. 2.8) and check the stationarity again. The value of P = 3.8%, which is less than 5% and confirms the stationary nature of the series.



Img. 2.8 – Log Dickey-Fuller test

Visual analysis of the data makes it possible to make assumptions about periodicity in the studied data series. To check, use the program Statistica Portable, select the menu Statistics / Advanced LinearNonlinear Models / Time Series Forecasting / Spectral (Fourier) Analysis and build a periodic chart Img. 2.9. A sharp peak indicates the presence of regular cycles and gentle peaks - irregular cycles. Thus, the studied time series contains two regular cycles with a period of 7 days and 125 days. Also, there is an irregular cycle, with a frequency of 65 days.



Img. 2.9 – Periodogram

A cycle lasting seven days confirms that fewer PCR tests are done during the weekend, so these are the statistics. A cycle of 125 days is a seasonal wave of morbidity in 4 months without preventive vaccinations. That is, if there is no preventive work to combat Covid-19, it is likely that the next wave of cases will be repeated every four months.

2.4. Model building

Regression [39] is a way to describe and display the form of dependence between two objects Y and X, where Y depends on X. The regression relationship is described in formula (2), adding coefficients that represent the value by which the object Y increases on average if the object X increases by one unit. As a result, we can formulate a formula that can predict the behavior of object Y with respect to changes in object X:

$$Y = a + bx \tag{2}$$

X is called an independent variable, Y is a dependent variable. This is the value we expect for y (on average) if we know the value of x, ie, it is the predicted value of y, a is the free member (intersection) of the evaluation line; this value is Y, when x = 0, b is the angular coefficient or gradient of the estimated line; it is the value by which Y increases on average if we increase x by one unit. In our case, using the MS Excel package, we obtain a regression (3). It follows that there is a general tendency to increase the number of infected by 1.2 on average in one day.

$$Y_{j:=1.2j+8001.8} \tag{3}$$

We use the MathCad application package to analyze harmonic oscillations, which allows us to perform a Fourier series expansion (4). Harmonic analysis (analysis using Fourier series) is based on the fact that a time series can be represented as the sum of harmonics. Usually, the sum of harmonics is not limited, but, as a rule, only significant ones are taken, which reveal the most characteristic regularities of the time series [40].

$$f(t) = \frac{a_0}{2} + \sum_{k=1}^{\infty} A_k \cos(k\frac{2\pi t}{T} + \theta_k) \tag{4}$$

Where f (t) is the seasonal component, a_0 – free member, k – harmonic number, A_k- oscillation amplitude, $\frac{2\pi t}{T}$ – frequency, θ_k - phase of the k-th oscillation.

Thus, the use of harmonic analysis is reduced to the calculation of harmonics to determine the most significant of the equations of cyclic components of the series.

First, import the original data to the matrix W (Img 2.10), then calculate the linear trend and consider the graphs, displaying the series of our data, the trend, and the series cleared of the trend (5).

$$j := 0..255 \qquad W := \text{1.txt}$$

$$M_j := W_j$$

$$Y_j := 1.2 \cdot j + 8001.8$$

$$Q_j := M_j - Y_j$$

Img.2.10 - Calculations in MathCad

$$Q_j := M_j - Y_j \tag{5}$$

Yj - linear regression equation for the last 256 days, Qj - series calculation operator without trend

In Mathcad, there is a function of fast decomposition of the Fourier series. To use this function, the number of members of the series must be equal to 2n, where n is a natural number. We use 256 rows of data, which is quite suitable for decomposing the Fourier series (27). Using the operator fft (fast Fourier transform), we find the harmonics U of the Fourier series. In our case, there will be 128 harmonics, but there will be only three significant ones: the second, the thirty-sixth, and the thirty-seventh. Their significance is reflected in the most significant numbers (Img.2.11).

$i := 0..255$

$TMP_i := Q_i$

$U := fft(TMP)$

$k := 0..128$

$U^T =$

	1	2	3
0	-3.89·10³-47.494i	-4.081·10⁴-5.505i·10³	...

$\overrightarrow{(|U|)^2}^T =$

	0	1	2	3	4	5
0	830.881	1.514·10⁷	1.696·10⁹	4.145·10⁷	6.843·10⁷	...

$UU = (U_2 \ U_{36} \ U_{37})$

Img. 2.11 - fast fourier transform (fft)

Therefore, to study the cyclic component, we use 2; 36 and 37 harmonics. All other fluctuations are considered insignificant and are not used in the calculations. Now we calculate the coefficients Am (6) and Fq (7) of the Fourier series and compare the equation of the cyclic component (8).

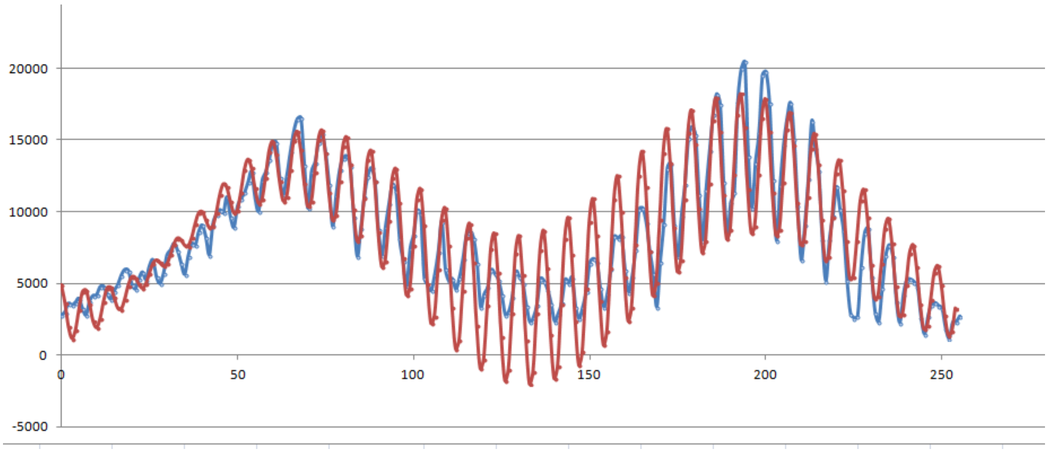
$$\mathrm{Am} = \frac{|U_k|}{e} \tag{6}$$

$$\mathrm{Fq} = \arg(U_k) \tag{7}$$

$$f(t) = 5021\cos\left(\frac{1}{64}\pi x - 0{,}51\right) + 2536\cos\left(\frac{9}{32}\pi x - 1{,}17\right) + +3059\cos\left(\frac{37}{128}\pi t + 1,2654\right) \tag{8}$$

Now we return the trend to model (9) and obtain a general formula for further prediction of the phenomenon of "number of infected per day" for 256 days.

$$f(t) = 5021\cos\left(\frac{2}{256}\pi x - 0{,}51\right) + 2536\cos\left(\frac{36}{256}\pi x - 1{,}17\right) + 3059\left(\frac{37}{256}\pi t + 1,2654\right) + 1.2j + 8001.8 \tag{9}$$



Img. 2.12 – Plot Model

Img 2.12 presents a graphical comparison of empirical results (blue) and theoretical values (red line) obtained using formula (9).

2.5. Model adequacy check and results

To justify that, we can use model (9) to predict further the phenomenon of "population morbidity from Covid - 19", we will check the quality of the model using the coefficient of determination (10) and Fisher's test. The coefficient of determination R^2 indicates the share of the variability of the factor described by the model.:

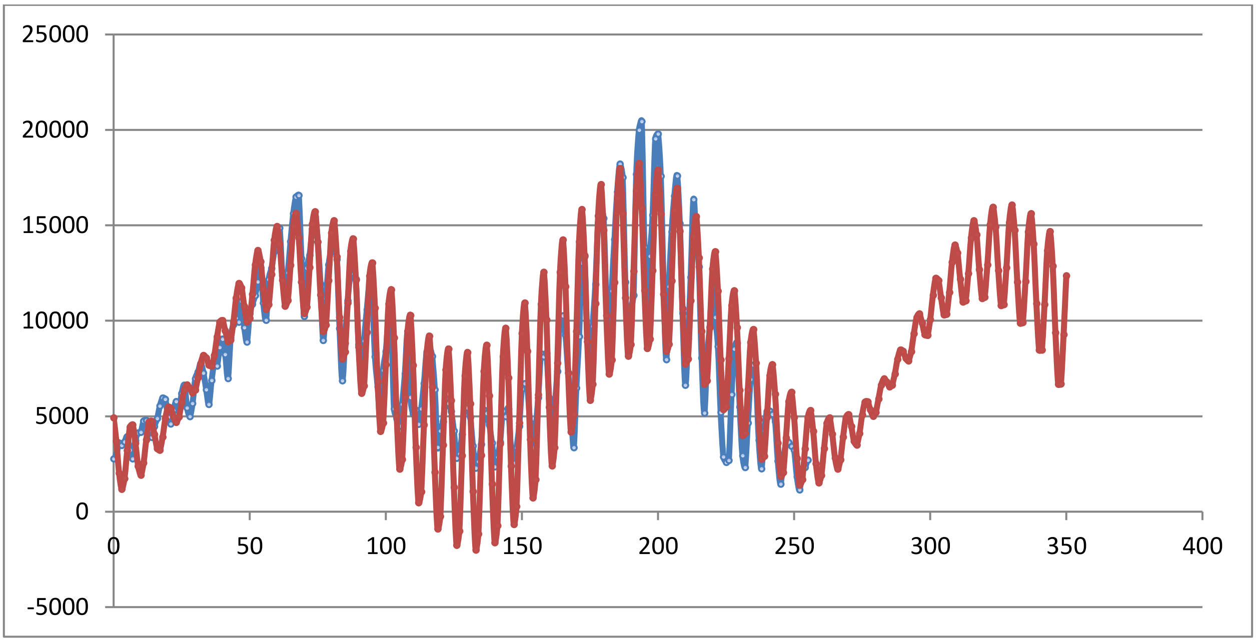
$$R^2 = \frac{\sum_1^{256}(\hat{y}_i - \bar{y})^2}{\sum_1^{256}(y_i - \bar{y})^2} \quad (10)$$

Where y_i is the empirical data chosen for the study, $\hat{y}_i$ is theoretical data, obtained by the formula (9), $\bar{y}$ is average value of all levels. After performing the calculation we get the value $R^2 = 0.91$, indicating the high degree of quality of the model, model (10) explains 91% of the variability of the indicator "number of infected" depending on the day.

Let's check the quality of the model using Fisher's criterion (11), which indicates the statistical significance of our model.

$$F = \frac{R^2}{1-R^2} \cdot \frac{n-m-1}{m} \quad (11)$$

Where R^2 is Coefficient of determination, m - the number of parameters for variables X, n – number of observations. Determine the tabular value of the Fisher criterion and the significance level $\alpha = 5\%$ for the number of degrees of freedom k1 = 1 and k2 =300: $F_{tab} = 3{,}87.$. After calculations by formula (11) we obtained the value F = 2568.22, which is much larger than $Ftab$ and confirms the statistical significance of the parameters.



Img. – 2.13 – Forecasting next 100 days

Thus, the constructed model (9) is statistically significant by Fisher's test and explains more than ninety percent of the variability of empirical data, which allows us to conclude that the model has a sufficient level of adequacy and to calculate predictive values for $\left[\frac{256}{3}\right]$=85 days shown in the Img. 2.13.

Analyzing the forecast model (Img. - 2.13), we can conclude that mid-August - early September is likely to expect a new wave of morbidity. The growing number of patients with Covid-19 poses new challenges for the medical sector in the number of free beds and may lead to new quarantine restrictions for the public and businesses. It is possible to stop or prevent lockdown and a new wave of coronavirus with the help of carefully planned preventive work to build collective immunity to the disease by mass vaccinations.

CONCLUSIONS

The study analyzes the current literature on issues related to the COVID-19 pandemic. Scientists around the world have changed the direction of their interests in the context of the pandemic. The dispersion of COVID-19 interests is very significant in any area affected by the pandemic: medicine and pharmaceuticals, primarily to combat the disease itself. The global economic crisis is forcing economists worldwide to focus on estimating the magnitude of losses, possible options for leveling the adverse effects and finding cause-and-effect relationships of differentiated effects. Special attention of world scientists is focused on forecasting future conditions for timely prevention.

A special place in modern research on pandemics is given to forecasting future conditions. The emergence of such a virus, which transforms the whole world - no one could predict. However, now many researchers aim to help governments prepare in advance for new, possible waves. Among the standard methodologies for forecasting the consequences are the models SEIR, ARIMA, the Holt-Winters model, the Prophet model, TVAT, which have their advantages and disadvantages. However, the trigonometric component and the trend component are actively used for seasonal forecasting, so the harmonic analysis of the Fourier transform was chosen for further study.

To model and predict the phenomena associated with any epidemiological situation, indicators such as the total number of infected and the number of deaths per unit time were considered. These two factors, mortality, and morbidity are interrelated. For another modeling, the indicator was chosen - the number of infected, as a more accurate, which was investigated for periodicity and stationary.

To analyze the harmonic oscillations, we performed a Fourier series decomposition with the removal of the trend component, which has a linear form.

The constructed model turned out to be statistically significant, which explains more than ninety percent of the variability of empirical data..

Analyzing the forecast model, we can conclude that in mid-August - early September is likely to expect a new wave of disease. The growing number of patients with Covid-19 poses new challenges for the medical sector in the number of free beds and may lead to new quarantine restrictions for the public and businesses. Carefully planned preventive work to build collective immunity to the disease by mass vaccinations can be stopped or prevented by lockdown and a new wave of coronavirus.

To prevent the spread of the virus, it is better to refrain from traveling Follow the recommendations for citizens regarding the crown of the virus by the Ministry of Health, avoid mass events, stimulate vaccination measures against the virus to build public immunity.

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APPENDIX

Appendix A

Summary

Marchenko R.V. Forecasting the dynamics of COVID-19 in Ukraine based on harmonic analysis Qualifying work of the bachelor. Sumy State University, Sumy, 2021.

The study's primary purpose is to develop an economic and mathematical model for predicting the incidence of COVID-19. The urgency of solving this scientific problem is that the pandemic situation in Ukraine showed insufficient readiness of the health care system to respond quickly to crises, the low financial security of most municipal primary and secondary care, which was reflected at least in the low level of material support, etc. . The methodological tools of the study were methods of searching and collecting statistics with further use to develop a model based on harmonic analysis and forecasting of time series, the study period selected "the number of new cases of Covid-19 per day" from January 22, 2020 to May 2, 2021 year. The country of Ukraine was chosen as the object of the study because it has a significant influence on the spread of infection caused by the COVID-19 virus. The article presents the results of empirical analysis R2 = 0.91, which indicates a high degree of quality of the model. The model explains 91% of the indicator "number of infected" variability depending on the day. The results of this study can be helpful for students of economics, academics, enterprises, and organizations of all forms of ownership in the analysis of the impact of Covid-19.

Keywords: Forecasting, time series, modeling, economics, virus, Covid-19, Fourier, statistics, morbidity, mortality, Python, MathCad, API

Key words: Forecasting, time series, simulation, economics, virus, Covid-19, Fourier, statistics, morbidity, mortality, Python, MathCad, API

Анотація

Марченко Р.В. . Прогнозування динаміки розвитку COVID-19 в Україні на основі гармонійного аналізу. Кваліфікаційна робота бакалавра. Сумський державний університет, Суми, 2021Р.

Основною метою проведеного дослідження є розробити економіко-математичну модель для прогнозування рівня захворюваності від COVID-19. Актуальність вирішення даної наукової проблеми полягає в тому, що пандемічна ситуація в Україні виявила недостатню готовність системи охорони здоров'я до оперативного реагування на кризові ситуації, низьку фінансову забезпеченість більшості муніципальних установ первинної і вторинної медичної допомоги, що відображалось щонайменше у низькому рівні матеріальної підтримки тощо. Методичним інструментарієм проведеного дослідження стали методи пошуку та збору статистичних даних з подальшим використанням для розробки моделі на основі гармонійного аналізу та прогнозування часових рядів, періодом дослідження обрано «кількість нових випадків захворювань на Covid-19 за добу» з 22 січня 2020 року по 2 травня 2021 року. Об'єктом дослідження обрана країна Україна, оскільки вона має великий вплив від поширення інфекції спричиненим вірусом COVID-19. В статті представлено результати емпіричного аналізу R^2 = 0.91, що вказує на високу ступінь якості моделі, модель пояснює 91 % мінливості показника «кількість інфікованих» в залежності від дня. Результати проведеного дослідження можуть бути корисними для студентів економічних факультетів, науковців, підприємств та організацій всіх форм власності при аналізі впливу Covid-19.

Ключові слова: Прогнозування, часові ряди, моделювання, економіка, вірус, Covid-19, Фур'є, статистика, захворюваність, смертність, Python, MathCad, API