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Article

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Economy and forecasting

https://doi.org/10.15407/econforecast.2022.01.31
JEL: H510; H75; I180

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IMPROVING THE SYSTEM OF INDICATORS FOR ASSESSING THE EPIDEMIOLOGICAL SITUATION AND STRENGTHENING RESTRICTIVE MEASURES IN THE CONDITIONS OF ADAPTIVE QUARANTINE CAUSED BY THE SPREAD OF COVID-19

The article deals with the problem of the effectiveness of the state response to challenges to the health care system due to the spread of infection caused by SARS-CoV-2. The authors have carried out an analysis of international economic investigations on its impact on the socio-economic system in general and the health care system in particular. It was found that the vast majority of them examine the impact of various factors on the spread of coronavirus or its effects on individual segments or the economic system as a whole, the response of the decision-making system to the spread of infection, or model different scenarios for health system challenges. However, investigations do not address what criteria should be applied when imposing restrictive measures or what changes need to be done to the threat assessment system to minimize the burden on the health care system. Therefore, the authors analyzed the current national indicators system used to identify regions with a high prevalence of SARS-CoV-2. Based on a retrospective analysis of previous waves of coronavirus spread in Ukraine and the introduction of quarantine restrictions in this regard, it was found that the decision to strengthen quarantine restrictions was delayed. This overloaded the medical system and led to overcrowding, which could have been avoided if quarantine had been introduced early. It is revealed what changes in the assessment methodology need to be made in order to strengthen the quarantine restrictions in time. An assessment of the filling of the hospital stock under the condition of timely introduction of quarantine on the example of the city of Kyiv was carried out and the cost of

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redundant hospitalizations was estimated. Changes in the current methodology for estimating regions with a high prevalence of SARS-CoV-2 are proposed, which include the introduction of additional indicators and quantitative changes for existing indicators.

Keywords: *quarantine measures; pandemic; decision-making system; level of hospitalizations; PCR testing; hospital congestion*

Effective control of the spread of SARS-CoV-2 coronavirus infection is one of the urgent tasks of the government in general and the health system in particular. The health system and the Cabinet of Ministers of Ukraine are responsible for developing a methodology for determining the extent of the spread of coronavirus in the regions. In Ukraine, in order to minimize risks not only to the health system but also to the economy as a whole, an adaptive quarantine strategy was introduced since February 2021, with the introduction of "green", "yellow", "orange" and "red" levels of epidemiological safety. Low vaccination rates of the population, increased seasonal factors, Christmas and New Year's celebrations, and the emergence of a new Omicron strain with higher transmissibility created additional risks for the medical system during the winter and spring 2022. The evolution of the coronavirus during the third (February-April 2021) wave caused by the British strain and the fourth (September-December 2021) wave caused by the Delta strain, revealed a number of gaps in the decision-making system, leading to significant delays in imposing the more stringent restrictions. Analysis of the indicators that are taken into account when identifying regions with high COVID-19 prevalence is therefore of paramount importance.

Existing models for predicting the spread of coronavirus disease are almost exclusively focused on indicators of total morbidity and mortality due to infection with the virus. At the same time, much less attention is paid to forecasting the burden on the hospital stock and the timely implementation of measures by the government and local authorities to prevent the collapse of the medical system.

The purpose of this study is to identify the shortcomings of the existing methodology for assessing the epidemiological situation, which are manifested during the rising wave with the rapid growth of new cases, which leads to a delay in the introduction of restrictive measures and excessive load on the hospital stock.

In this survey, we consider the main indicators used by the Ministry of Health to strengthen the quarantine, and based on the retrospective analysis of previous waves, we propose changes to the existing methodology for the introduction of restrictive measures in order to reduce the burden on the medical system. The introduction of new indicators in addition to the existing ones will make it possible to predict the maximum of the capabilities of the medical system more effectively and introduce timely reinforcement of quarantine.

Research analysis. Due to the spread of the SARS-CoV-2 pandemic, there are many publications in various countries covering different aspects of the impact of the pandemic on the economies. Ukraine’s economic research has mainly focused on the impact of the pandemic on certain economic sectors, incentive mechanisms, and the experience of foreign countries in overcoming the consequences of the quarantine measures [1, 2]. Various issues of budgetary opportunities were considered, such as ones for establishing production of own vaccines, improving the decision-making system to counter COVID-19 through state regulation based on the analysis of measures conducted by different countries, challenges for the health care system related to the introduction of restrictive measures, testing level, and others. [3-5].

Forecast of the development of the COVID-19 epidemic in Ukraine on the basis of time series is regularly developed by the Institute of Mathematical Machines and Systems Problems of the Ukraine National Academy of Science [6]. Although the analytical part of this forecast uses data not only on morbidity or mortality, but also on the number of hospitalized patients in previous periods, its prognostic part lacks data on the potential occupancy of hospitals. Also, the forecast does not consider the implementation of quarantine restrictions, which have a significant impact on the dynamics of morbidity and hospital admissions. Most importantly, it does not answer what needs to be changed in the decision-making system for strengthening quarantine restrictions to avoid overload in the medical system observed during each new wave of coronavirus at local or all-Ukrainian levels.

The problem of effective decision-making in the application of different response scenarios to the coronavirus infection spread is not unique to Ukraine. For example, during the first wave of the pandemic caused by the Wuhan virus strain, the medical system collapsed in Italy, France, Spain, and the USA. A sharp increase in hospital admissions, lack of oxygen supply to all beds, and overcrowded hospitals led to a high mortality rate in European countries. However, even given the experience of the first wave of the pandemic, during new waves countries occasionally lose the ability to provide hospital care to all patients who need it. Therefore, the search continues for optimal solutions to prevent the medical system from exceeding its maximum capacity. In the USA, for example, studies were carried out on different trajectories of hospital admission depending on scenario conditions (vaccination rates, age groups, population behavior) and the response of the decision-making system to increasing numbers of patients, in which certain rules were developed that local communities can use to predict hospital admissions within 1-2 months [7].

In Brazil, public spending on hospitalization for COVID-19 treatment was analyzed in 2020. Among other things, the study discovered that the rate of fatalities among hospitalized people rose in the region with the higher rate of hospital admissions. The average length of hospitalization and the average cost of treatment also increased. Consequently, increasing pressure on the health-care system provokes other interrelated negative consequences [8].

Another study showed that timely blocking of social contacts could divide the peak of hospitalizations into two peaks less distant from each other, lengthening the overall duration of the pandemic wave and reducing strain on the medical system [9]. When considering pandemic scenarios within the Brazilian federal district, the effect of social distancing measures on the need for beds in the intensive care unit [10] was shown.

Polish researchers analyzing two strategies - zero-tolerance (China, South Korea, Japan) and suppression (European countries, the USA) - concluded that intensive contact tracing and increased testing while reducing the positivity rate can reduce transmission to a value below unity without increasing restrictive measures [11]. A similar study of restriction strategies (elimination and suppression/mitigation) was carried out by German researchers. According to it, the growth benefits of the elimination strategy become indirectly visible due to mortality rates, as these countries record near-zero mortality rates [12]. In contrast, countries with a suppression/mitigation strategy (especially smaller countries such as Switzerland, Hungary, the Czech Republic, and Slovenia) showed a decrease in total cases amidst an increase in mortality rates.

In a study of the mobility restrictions impact on regional GDP, Italian researchers found a strong correlation between a decrease in mobility and a decrease in GDP per capita, and this impact was observed independently of the economic development of Italian provinces [13]. This close correlation can serve as a criterion for a preliminary assessment of the negative impact of restrictions on regional economic conditions, almost in real time, prior to the publication of official statistics on GDP, which is published with a significant delay. A similar approach was used in the creation of a multi-factor monthly industrial production model for economic monitoring based on mobility data [14].

Spanish researchers compared different scenarios for counteracting the spread of the pandemic, such as increased testing and strict quarantine restrictions [15]. Both scenarios involve reductions in new cases, hospitalizations and deaths. In the first case, however, the costs of increasing testing capacity must be increased. The second scenario is fraught with negative consequences, such as a drop in GDP, a decrease in economic activities, a decrease in the quality of education, and a decline in certain economic activities, which could become much costlier as a result.

The question therefore arises how to combine the different scenarios to minimize the negative impact on the economy and public health. However, British researchers found that ill-conceived extensions of quarantine measures result in costs that are several times greater than the benefits of potentially saved lives [16].

A study of infection risk factors in selected Spanish regions showed the importance of the population demographic structure, the level of urbanization, and the intensity of socioeconomic activity [17]. This is primarily due to the increasing number of social interactions in large cities, where the socio-economic activities involved are concentrated (e.g. shopping malls). Consequently, approaches to the implementation of restrictive measures in different parts of the region must differ according to the degree of risk. Such conclusions are also relevant in Ukraine, where the effects of using unified generalized criteria for assessing the spread of coronavirus infection when strengthening restrictive measures for individual regions differ significantly. While some regions (predominantly megacities) suffer from health system overload during another wave, others follow a more optimistic scenario. A large-scale study of 500 US cities showed that mortality risks increase in communities where the percentage of chronic diseases is higher [18]. If chronic diseases are associated with an unfavorable environment (air or water pollution, economic instability, low availability and quality of health care, social tensions, etc.), such regions should be classified as areas with potentially high mortality and risk of coronavirus disease. For Ukrainian realities, such differentiation would also be appropriate.

Among the new approaches to investigate the negative impact of COVID-19 is bio-economic optimization, which combines epidemiological and economic approaches and considers multi-criteria decisions. An example of this approach is the researchers' modelling of quarantine removal for Toulouse, a French city of 475.000 inhabitants, under different scenarios, and the evaluation of the best long-term strategies to establish what policy levers should be used to minimize the negative long-term impact [19]. The bio-economic approach takes into account both the demographic and socio-professional profiles of the inhabitants and focuses on the trade-offs between the constraints of economic impact and the well-being of different groups. The main finding of this research is that policy makers should focus more on individual behavior rather than trying to optimize a blocking strategy. Social distance is recognized as a key parameter for limiting the spread of disease. Thus, the main challenge is to maintain social distance through appropriate individual behavior without the excessive forced social distancing implemented by the government, which is very often associated with high economic power. In countries with poor socio-economic conditions, strict social distancing measures and generous income support programs reduce the number of cases and deaths. However, hospital saturation and public health remain a key political risk in decisions to impose severe restrictions on quarantine policies.

Another example of bio-economic optimization is the incorporation of social determinants into compartmentalized biological models, which can improve the predictive power and accuracy of modelling both the dynamics of infection and the severity of the epidemic in question. Moreover, it can help us understand the impact of different welfare regimes on the effectiveness of a given set of restrictive measures undertaken by governments. For example, British researchers used employment conditions, living conditions, and access to and quality of health infrastructure as social determinants [20]. Incorporating social determinants into standard biological models improves predictive accuracy and explains significant differences in hospital admissions and mortality rates within the same country.

Ukraine chose an adaptive quarantine strategy to fight the spread of COVID-19, which involves monitoring the epidemiological situation in the regions and is designed to introduce restrictive measures to prevent the collapse of the medical system. This approach allows flexibility in imposing restrictions in different regions and for shorter periods of time, considering the epidemiological situation. However, despite the existence of a transparent methodology, its application does not prevent overload of the medical system, and reinforcement of quarantine restrictions occurs with considerable delay.

The rapid spread of coronavirus infection in the spring of 2021 led to a collapse of the medical system in some regions. Hospital bed occupancy rate far exceeded the capacity of the medical system. As a result of the shortage of beds, triage of patients actually took place at the stage of calling an ambulance. In the hospitals, however, doctors were forced to reduce the number of patients on their beds in order to reach more patients in need of help. The same situation was observed in some regions of Ukraine (Lviv, Odesa, Kharkiv, Kherson, and Mykolaiv regions) during the fourth wave caused by the Delta strain, which is characterized by a more rapid progression of disease and complications and affects younger patients. Consequently, hospital bed occupancy rate was also higher than during previous waves.

The review of current Ukrainian assessment methodology of a region with wide dissemination of COVID-19

According to the Resolution of the Cabinet of Ministers of Ukraine of 09.12.2020 No1236 "On establishment of quarantine and implementation of restrictive anti-epidemic measures to prevent the spread of acute respiratory disease COVID-19 caused by SARS-CoV-2 coronavirus in Ukraine" [21], the basic values that are taken into account when establishing the epidemic risk level are such indicators as:

– the number of new COVID-19 infections detected per 100,000 populations;

– COVID-19 case detection rate (by polymerase chain reaction and SARS-CoV-2 rapid antigen test);

– the number of polymerase chain reaction tests and SARS-CoV-2 rapid antigen test;

– oxygen bed occupancy rates in health care facilities identified for hospitalization of patients with a confirmed case of COVID-19;

– the number of patients hospitalized with a confirmed and suspected case of COVID-19 in the last seven days per 100,000 people;

– the level of total hospital admissions for confirmed and suspected COVID-19 cases in the last seven days compared to previous comparable period.

Such indicators generally well reflect changes in the level of epidemic risk, but when there is a rapid spread of infection, there is a delay in the change in indicators. This is due to the following factors:

1. With the rapid spread of infection during the rising wave, testing rates lag far behind the rate of disease. As Ukraine does significantly less testing than developed countries, the number of new infections detected depends on testing number. Consequently, the incidence rate is underestimated during the rising wave period.

2. In most countries, only polymerase chain reaction tests are used to define the COVID-19 infection rate, as SARS-CoV-2 rapid antigen test is an auxiliary test. Therefore, the actual case detection rate is much higher than the values used to determine the epidemiological risk level.

3. Data from all laboratories producing PCR tests, including private laboratories, are taken to assess the real picture with the detection rate of infections. This underestimates the value of the ratio. In fact, the prevalence rate is determined primarily by the positivity rate obtained from tests in state-run free-of-charge regional laboratory centers. A high positivity rate in them indicates not only the spread of infection in the region, but also an insufficient level of testing, where samples are taken to the laboratory only when there is a clinical manifestation of COVID-19.

Due to the emergence of new, more contagious strains, countries are changing approaches to mandatory testing protocols for contacts. In Poland, for example, mandatory COVID-19 testing of all persons living with an infected person is being implemented, even regardless of the existence of a vaccination certificate or past illness [22, 23]. Also, testing of workers in a wide range of professions is being established. The capacity of the Polish health care system is about 200,000 tests per day [24]. In Ukraine, however, contact persons (family members living with the patient) are deprived of the opportunity to be tested free of charge in the absence of symptoms. In large cities (Kyiv, Dnipro, Kharkiv, Odesa, Lviv), the financial resources of some residents allow them to do the appropriate tests at their own expense in the private laboratories available. However, for the majority of regions state laboratory centers are the only way to conduct testing and the financial status of their residents is worse.

In most countries, a positive rate above 10% indicates a state of infection spread where severe restrictions need to be imposed. In Ukraine, at the peak of growth during the spring wave of 2021, PCR test positivity rates reached 40-45% on some days (in autumn 2020, the highest positivity was at 43%). During the current wave caused by the Delta strain, overall PCR test positivity rates of 48% were recorded (data for 01.11.2021).

If we look at the statistics of testing by regional laboratory centers available on the website of the Public Health Centre of the Ministry of Health across Ukrainian regions, we will see that the positivity on 13.10.21 exceeds 40% in most regions (Fig. 1).

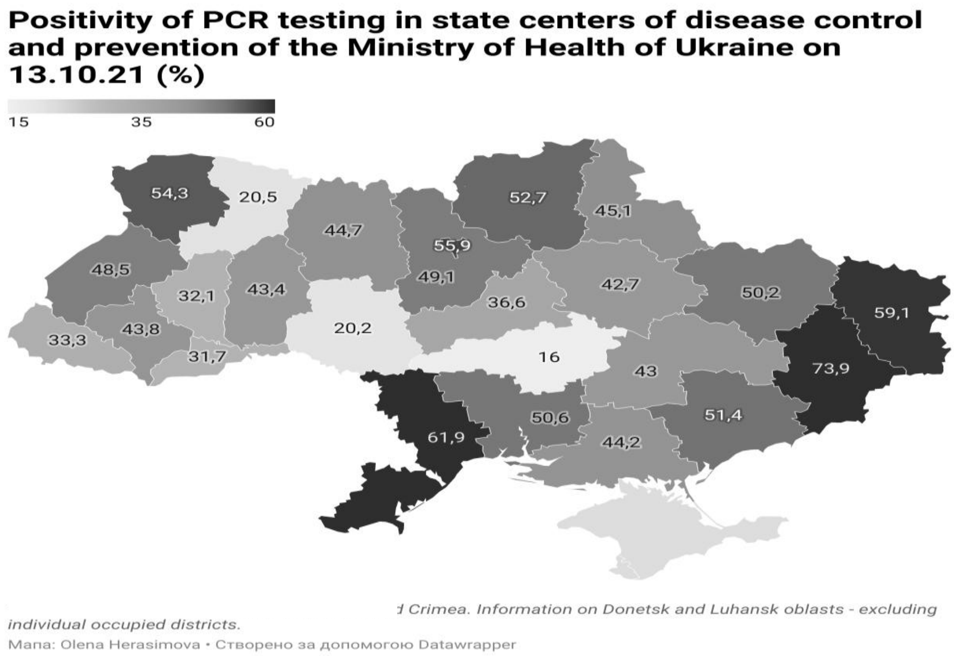

Figure 1. PCR testing in Ukrainian regions (oblast) on 13.10.21

Source: calculated and constructed by the authors on the basis of data from the Ministry of Health of Ukraine.

In a fortnight, the situation worsened considerably and more than half of the regions had PCR test positivity above 50%, and in Odesa and Kherson regions it exceeded 60% (Figure 2).

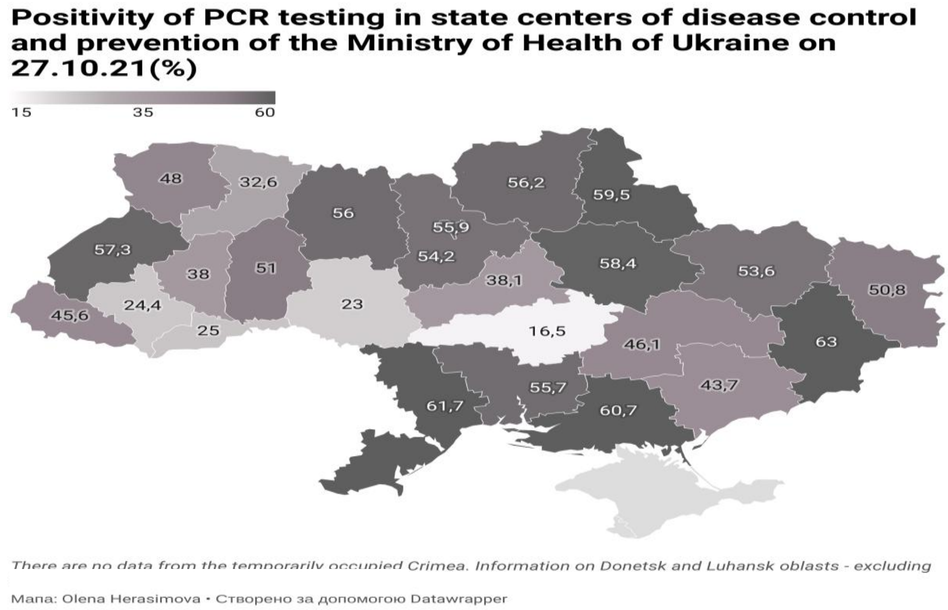

Figure 2. PCR testing in Ukrainian regions (oblast) on 27.10.21

Source: calculated and constructed by the authors on the basis of data from the Ministry of Health of Ukraine.

Thus, the positivity rate of PCR testing performed by public laboratory centers is more sensitive to changes in the spread of infection than the summary rate of PCR and antigen tests currently used in the Ministry of Health of Ukraine methodology.

Although antigen tests help to monitor the spread of coronavirus in the early stages of the disease, in the authors' opinion, they should not be included in the epidemiological situation assessment methodology for decisions on strengthening quarantine. Firstly, the testing coverage rate should firstly refer to the ability of the government to provide sufficient PCR testing in public laboratory centers, and the antigen tests are only an auxiliary tool to reduce the burden on the system in the absence of symptoms in the individual. Secondly, as such tests are performed outside laboratories, there is also no quality control of the material taken, hence the reliability of the result is reduced (this also happens when biomaterial for PCR tests is taken by untrained staff [25]). Thirdly, some of the antigen tests are performed when a person needs either inpatient treatment not related to coronavirus disease or sanatorium treatment, or at airports, and in other cases. Therefore, the low positivity of antigen tests cannot reflect the real picture of disease prevalence, as it is used for a large group of individuals who do not fall into the category of suspected coronavirus infection. In addition, a number of studies show that, unlike PCR tests, up to 20% of antigen tests show a false-negative result [26, 27].

According to a decree of the Cabinet of Ministers of Ukraine, the COVID-19 case detection rate is calculated according to the formula:

$$k_p = \frac{PCR_p + AG_p}{PCR_{tot} + AG_{tot}}, \quad (1)$$

where PCR_p and AG_p – the number of positive PCR and Antigen tests, respectively, and PCR_{tot} and AG_{tot} – the total number of PCR and Antigen tests performed.

In the case of PCR testing, PCR_p and PCR_{tot} consist of two parts:

$$PCR_p = PCR_p^{new} + PCR_p^{rt} \quad (2)$$

$$PCR_{tot} = PCR_{tot}^{new} + PCR_{tot}^{rt}, \quad (3)$$

where the corresponding terms in equation (2) denote the number of new cases detected and the number of positive cases retested, and equation (3) denotes the total number of new cases and the total number of retests performed.

Obviously, retest results should not be included in the case detection rate.

Consequently, the calculation of the *k*-factor of equation (1) should look like this:

$$k_p = \frac{PCR_p^{new}}{PCR_{tot}^{new}} \quad (4).$$

In order to control the spread of infection, it is advisable to use a modified case detection rate, whose calculation is based only on data from public laboratory centers:

$$k_p' = \frac{PCR_p^{new}(gov)}{PCR_{tot}^{new}(gov)}, \quad (5)$$

where $PCR_p^{new}(gov)$ and $PCR_{tot}^{new}(gov)$ are respectively new cases detected and new tests carried out by the state regional laboratory centers.

A significant discrepancy between the coefficient values k_p and k_p' would indicate inadequate testing coverage in government centers and hence - an uncontrolled spread of the epidemic.

When the positivity of PCR testing becomes high, the official number of new cases is significantly underestimated in relation to the actual number of cases. Hospitalization rates should then be used to estimate the number of new cases (assuming sufficient hospital beds are available, as discussed below). Usually in previous waves the hospitalization rate was less than 0.2

or 20% of the total number of patients (in foreign studies it is assumed that the hospitalization rate does not exceed 5-10% of the total number of patients). At the beginning of the new wave (second half of August 2021) caused by the Delta strain, an anomalous pattern was observed in some regions - the number of hospitalizations per week was close to the number of patients detected during the same period, and was even higher (e.g. in Kyiv in the second half of October 2021 the proportion of patients hospitalized ranged within 35-45% of officially detected patients). This indicates a substantial underreporting of official data that does not reflect the real picture of disease prevalence.

From 1.08.2021 to 1.11.2021, a total of 180,000 patients were sent to COVID hospitals, although 683,000 were officially sick. Even if the proportion of hospital admissions was 20% of total, the official statistics are underestimated by at least 2,000. Consequently, with a high level of positivity of PCR testing, the rate of detection of new cases is no longer relevant. Therefore, when test positivity increases and the number of detected patients is underestimated, the hospitalization rate can be used to estimate the real number of patients in a certain period. However, this works only when the occupancy rate of hospitals allows new patients to be placed on treatment without hindrance. When the departmental stock is almost full of patients, the situation changes and there is a transition to the so-called "walking ghost phase" - a state of false improvement that precedes the collapse of the system. This can take such forms as:

- reduced hospital admissions, as there is nowhere to accommodate new patients;
- reduced dynamics of hospital admissions;
- changes in hospital admission protocols, where patients are triaged not only within the health facility, but also when the ambulance is called, and hospital admission is attempted.

Thus, when the system in a region is approaching collapse, the indicators (hospitalization rate and dynamics of hospitalization rate) temporarily show decreasing values, which postpones the region's transition into the red zone. It should be noted that such changes will occur in parallel with an increase in the number of patients requiring oxygen support and the number of patients in intensive care units (ICUs). In such a situation, it is important to supplement the indicator system with additional parameters to ensure a timely response to an outbreak of COVID-19 in the region.

In addition, when additional beds are deployed in the region to accommodate new patients, the oxygen bed occupancy rate is also temporarily reduced. Therefore, the region can also postpone the introduction of stricter restrictions, but this would not indicate an improvement in the epidemiological situation.

During the last autumn wave of 2021, caused by the Delta strain, the highest number of cases and hospitalizations was observed in Dnipropetrovsk and Kharkiv regions, and Kyiv city (Fig. 3).

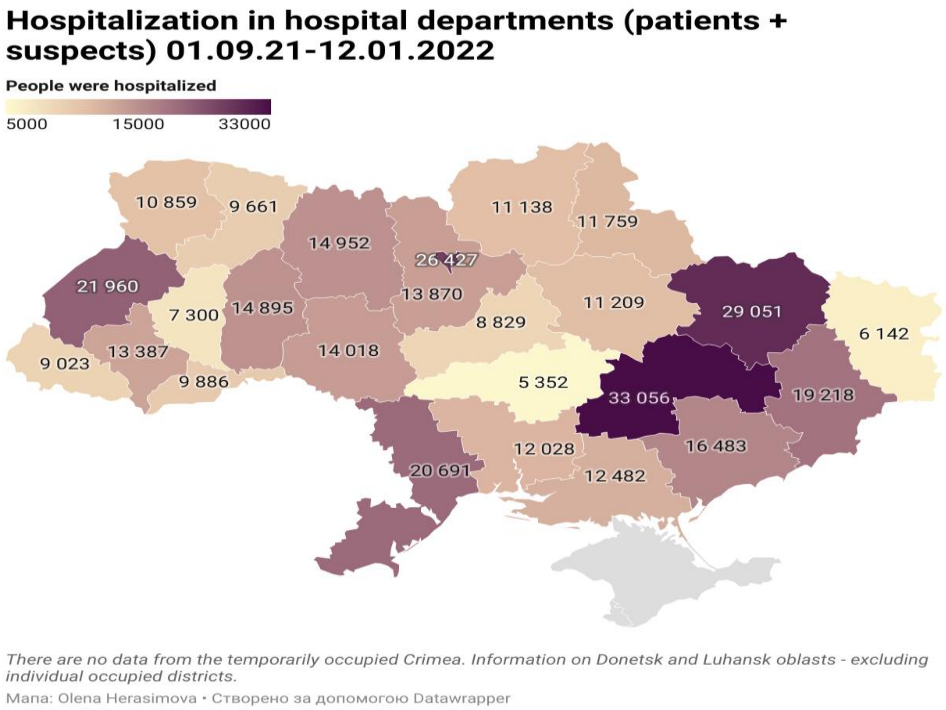

Figure 3. The total number of people hospitalized during the autumn wave of 2021

Source: calculated and constructed by the authors on the basis of data from the Ministry of Health of Ukraine.

However, decisions to increase restrictive measures in Dnipropetrovsk region and Kyiv were introduced with delays, and Kharkiv region did not introduce them at all, despite the overburdening of the medical system.

The dynamics of intensive care units (ICUs) occupancy by the example of the busiest regions (Kyiv, Dnipropetrovsk region and Kryvyi Rih) show that from a certain point the number of hospitals that exhausted their capacity (due to full occupancy of intensive care units) starts to grow, despite the overall increase in beds (Figure 4). For Kyiv this happened on 8-9 October, for Kryvyi Rih and Dnipropetrovsk region on 1-2 October.

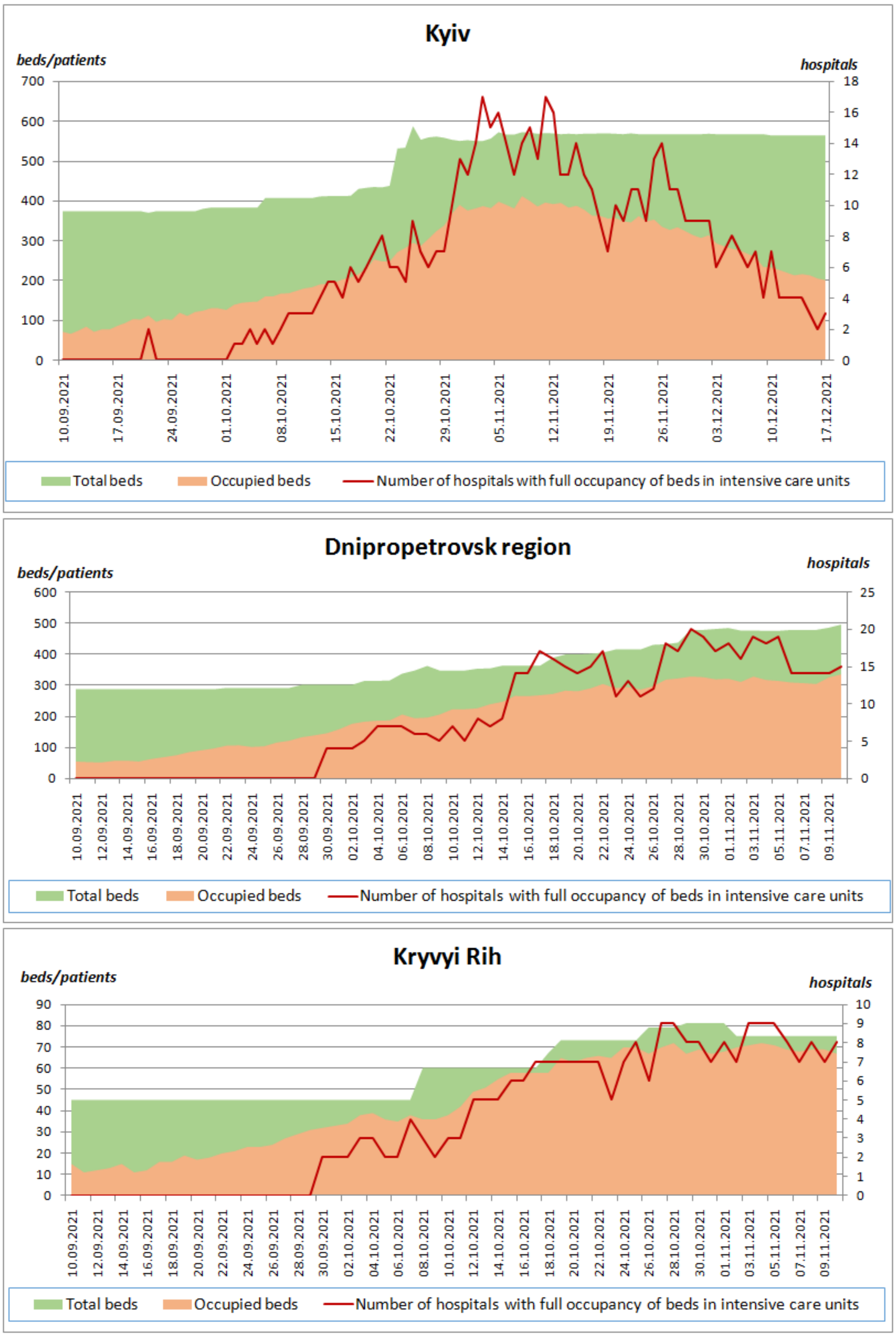

Figure 4. Hospitalization and occupation of intensive care units in autumn 2021

Source: calculated and constructed by the authors on the basis of data from the Ministry of Health of Ukraine.

Dnipropetrovsk region entered the red restriction zone only on 16 October, and Kyiv on 1 November. This means a delay of 2-3 weeks in decision-making. In Kharkiv region, 12-13 hospitals had full occupancy of beds in intensive care units in October (7-8 hospitals in Kharkiv every day). Despite the fact that hospitals were overloaded, the decision to implement the red restriction zone in the city was never made. Such examples demonstrate that the decision-making system for strengthening quarantine restrictions needs to be supplemented by monitoring the number of hospitals that reached their maximum intensive care units' occupancy, in addition to relying on average data for all hospitals in the region, which alone does not reflect the real picture.

It should be noted that there was inconsistency in the calculation of the daily number of new cases. Thus, the number of new cases, based on daily data from primary tests performed by certified laboratories and made public by the Center for Public Health of the Ministry of Health of Ukraine, differs significantly from the reports of the Ministry of Health of Ukraine (Figure 5).

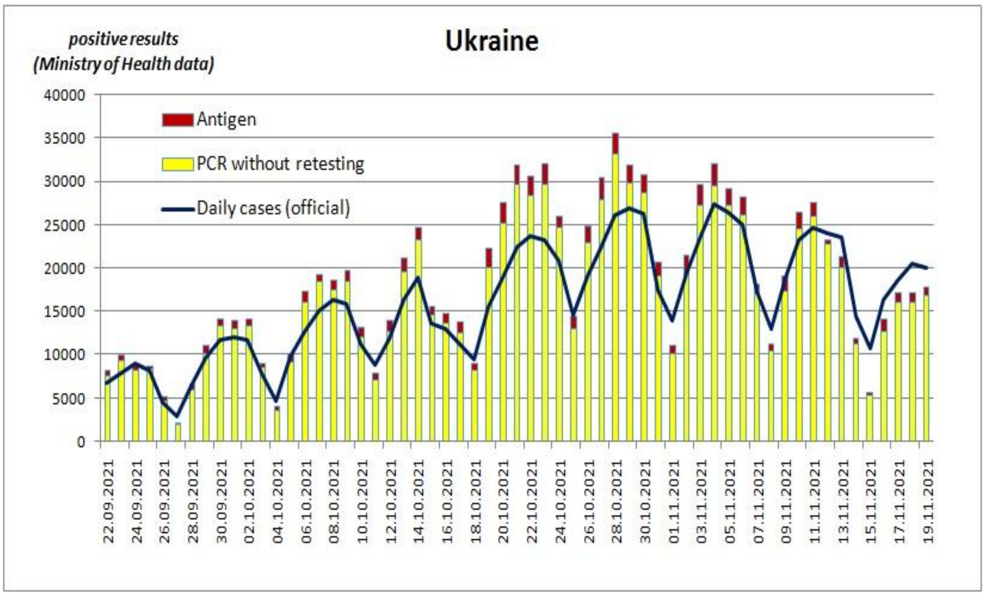

Figure 5. Daily detection rates of new cases of coronavirus in Ukraine

Source: calculated and constructed by the authors on the basis of data from the Center for Public Health of the Ministry of Health of Ukraine and operative information from the Ministry of Health of Ukraine on the spread and prevention of COVID-19.

This discrepancy makes it impossible to use the number of new cases as an indicator of the regional morbidity level. Furthermore, a derivative of this indicator is the current number of patients, which also becomes irrelevant. It is seen on the example of testing data in certified laboratories of Kyiv that the number of daily positive samples of PCR tests and antigen tests (without retesting) exceeds the official data on morbidity in Kyiv (Fig. 6).

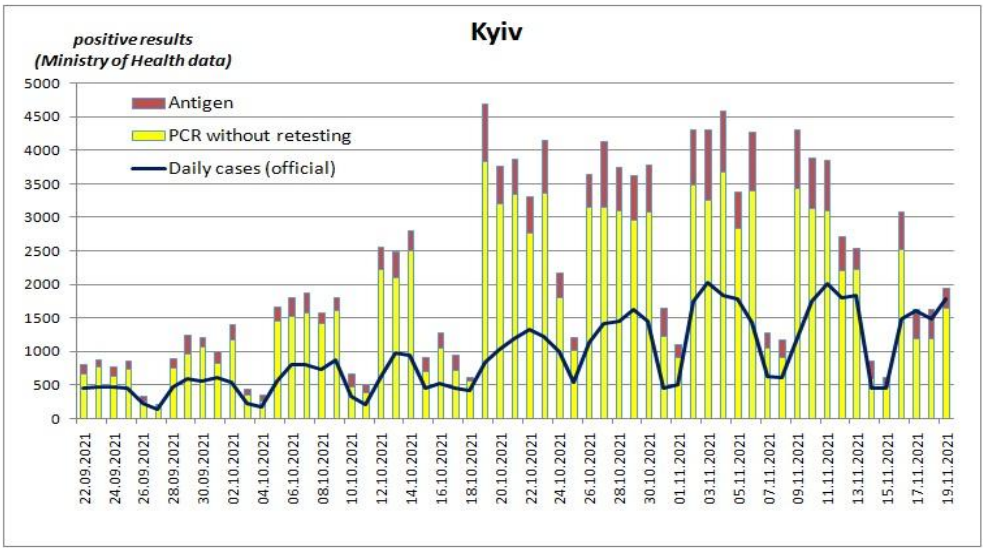

Figure 6. Daily detection rates of new cases of coronavirus in Kyiv

Source: calculated and constructed by the authors on the basis of data from the Center for Public Health of the Ministry of Health of Ukraine and operative information from the Ministry of Health of Ukraine on the spread and prevention of COVID-19.

In this case, it makes absolutely no difference why some of the patients detected by testing are not recorded in daily incident reports or are recorded with a significant delay (e.g. it might be because the official place of registration of the person tested is outside the capital, or officially confirmed new cases are entered into the system with a significant delay). While deciding on the introduction (or removal) of restrictive measures, the test-positivity indicators provided promptly by the laboratory should be used. Based on the data in Figure 6, it is clear that the introduction of stricter measures and the decision to implement the red restriction zone in the capital at the end of October was made with at least a three-week delay, when the official incidence data corresponded to the number of positive test results in the laboratories at the end of September. This delay led to an additional strain on the bed stock. According to the experience of previous epidemic waves, hospitalization rates stabilize in 10-14 days after the region is moved into the red restriction zone. If the decision to implement the red restriction zone in Kyiv had taken place three weeks earlier, the maximum bed occupancy rate could have been almost halved. Simulation of daily hospitalization rates based on the growth trends of previous epidemic waves in Kyiv under increased quarantine from 10 October 2021 allowed calculating the total number of excess hospitalizations (Figure 7).

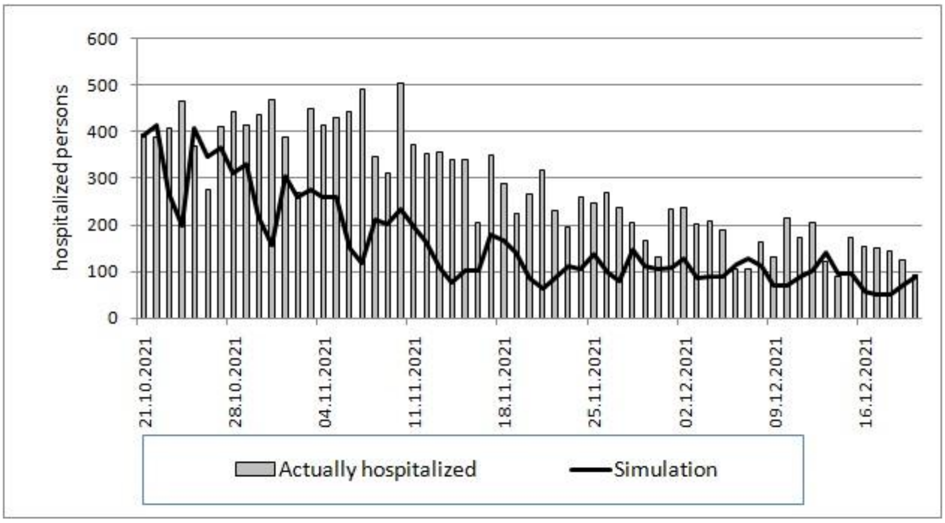

Figure 7. Indicators of the daily number of hospitalized in Kyiv and their simulation with the strengthening of restrictive measures from 10.10.21

Source: calculated by the authors.

The authors estimate that the untimely introduction of quarantine in the capital between mid-October and mid-December 2021 led to a rapid spread of infection and resulted in about 6,830 excess hospitalization. For the Kyiv health care system, the hospital treatment of the additional hospitalized patients cost more than UAH 150 million to taxpayers (based on the cost of hospital treatment of UAH 22,000 per patient [28]), or an average of UAH 2.5 million per day. For the economy of the capital city as a whole, the postponement of the quarantine cost tens of thousands of additional sick days and lost profits for numerous companies as a result of employee sickness.

The decision to impose restrictive measures abroad considers not only the occupancy of hospital beds to admit COVID-19 patients, but also the proportion of total patients. This approach is understandable, as overloading the entire medical system with co-morbidities leads to increased additional complications and deaths. Although that are not directly related to coronavirus disease, patients are unable to receive medical care in time as a result of the overcrowding of hospitals.

What is the critical level of bed occupancy for countries to start imposing the severest restrictions?

According to the Global Change Data Lab's[3] "Our World in Data" project, which compiles information on morbidity, vaccination, COVID-19 hospital admissions, and restrictions imposed, in developed countries a level of around 10% and lower occupancy of the total bed stock is generally considered critical for strengthening quarantine restrictions (see Table).

Table

Maximum occupancy rate of total beds in different countries during the spring wave of the 2021 pandemic

Countries	*% of bed occupancy*, from which the restrictions were reinforced	Maximum bed occupancy, *% of all beds*	Stringency index[4]	*The number of hospital beds per 1 million inhabitants*[5]
Austria	2.8	**3.1**	82.4	7370.0
Switzerland	2.5	**6.8**	60.2	4530.0
France	7.2	**7.7**	75.0	5980.0
Croatia	10.0	**11.0**	67.6	5540.0
Latvia	9.7	**11.1**	61.1	5570.0
Estonia	10.5	**11.9**	67.6	4690.0
Czech Republic	11.8	**13.4**	81.5	6630.0
Slovenia	12.2	**13.5**	81.5	4500.0
Poland	11.1	**13.9**	75.9	6620.0
Lithuania	10.5	**14.6**	74.1	6560.0
Hungary	11.0	**18.6**	79.6	7020.0
Serbia	18.0	**20.5**	61.1	5609.0
Bulgaria	16.9	**20.7**	61.1	7454.0
Ukraine	***21.6***	***28.5***	***66.7***	***4000.0***

Source: calculated by the authors on the basis of data from Global Change Data Lab. URL: https://ourworldindata.org/covid-hospitalizations

This low index (compared to Ukraine) is due to the fact that even after the introduction of severe restrictions for a certain period of time the rate of hospital occupancy is maintained. At the same time, depending on the overall level of morbidity, the growth in the number of occupied hospital

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[3] Our World in Data. URL: https://ourworldindata.org/coronavirus

[4] Comprehensive index, calculated on the basis of tracking policies in different countries and restrictions applied by governments to counter the spread of the pandemic SARS-CoV-2 (https://www.bsg.ox.ac.uk/research/research-projects/covid-19-government-response-tracker).

[5] For better comparability, the table provides data for countries where the bed occupation per 1 million inhabitants is as high as in Ukraine. The number of beds per 1 million inhabitants in Ukraine is based on data from the Ministry of Health of Ukraine on a total bed occupation of about 150,000 beds.

beds after the introduction of restrictions can vary from 20-30% to 2-3 times at the peak of the wave. In CEE countries, the maximum hospital occupancy rate was also almost half that of Ukraine. Even in Southern European countries (Bulgaria, Serbia), which had the worst morbidity and mortality rates among Central, Eastern and Southern European countries during the autumn wave of 2021, bed occupancy rates during peak wave were lower than in Ukraine despite a greater amount of bed stock per million inhabitants.

The countries that were more successful in dealing with another wave of COVID-19 were those that, in addition to the timely introduction of restrictive measures, additionally strengthened them for short periods (1-2 weeks). As can be seen from the table, despite the COVID-19 strain on hospitals, the restrictive measures in Ukraine could not be classified as severe. Due to this, their use was delayed for a longer period.

Conclusions

The analysis of the spread of coronavirus infection in Ukraine and the application of restrictive measures by the government when the disease is widespread reveals certain gaps in the methodology currently used to identify regions with high SARS-CoV-2 prevalence. In most regions, decisions to implement quarantine restrictions are taken late, when the medical system is already overwhelmed. Therefore, in order to avoid a collapse, it is necessary to change the approach in the indicator system regarding the order of transition of a region from one restriction zone to another:

1. In order to prevent the manipulation of bed occupancy rates, which are relevant indicators of the existing methodology, it is proposed to fix the calculation base of the available general fund, ruling out further upward changes in the base. After all, with the next wave in its growth phase, the implementation of new hospital capacity leads to a downward change in the bed occupancy rate. However, this does not indicate an improvement in the situation, but merely postpones the implementation of quarantine restrictions against the background of a constantly rising incidence of disease. The current calculation base for Ukraine is about 80,000 beds allocated to COVID-19 patients (in **Kyiv** about 6,000). The stocks for each region are proposed to be divided into three groups (approximately equal in volume):

– supporting hospitals that admit COVID-19 patients (for Kyiv, these are the Oleksandrivka clinical hospital and Kyiv City Clinical Hospitals 1 and 4);

– second wave hospitals, which are connected sequentially when the first group hospitals are 50% full;

– third wave hospitals, when the first and the second group hospitals are more than 40% full.

However, the restriction should be implemented when the second wave hospitals are involved, as the inertia of hospital admissions after the restrictive measures implementation persists for two to three weeks. If the restriction within two weeks does not lead to an improvement in the epidemiological situation and a reduction in the bed occupancy, especially in the ICUs, the restriction should be increased (in some cases up to a complete lockdown up to 7-10 days).

As it was noted earlier, most developed countries use *bed-place occupancy rate*, which on average is less than 10%, when governments decide to implement the severest restrictions in the country. For Ukraine, 10% of the total bed-place corresponds to COVID occupancy of the entire existing bed-place by 20%. This is the limit after which the country or its individual region should apply a red level of restrictions.

2. The use as an indicator of *hospital admission dynamics* is only appropriate if there are sufficient places to accommodate patients. Therefore, it is advisable to strengthen this indicator with the hospital occupancy rate for monitoring purposes. An improvement in the situation will be indicated by a negative trend in both indicators. If the rate of hospitalization is falling and the hospital occupancy rate is not decreasing, the system is already in a state of collapse. The same applies to the *oxygen bed occupancy rates.*

3. The methodology should be supplemented by additional indicators, such as *the percentage of ICUs occupancy and the number of hospitals that reached 100% occupancy*. The volume of bed stock of such departments is insignificant - about 7% of the total COVID fund. However, if the disease progresses rapidly, the need for such beds may be considerably greater and the length of stay in such units may be considerably longer than in general infection wards. A retrospective analysis of previous waves showed that such wards fill up more quickly and remain filled longer than in therapeutic wards. Their occupancy rate of 20% (see Figure 4) was a critical indicator, at which the number of hospitals with the maximum occupancy rate and the bed occupancy rate increased despite the increase in the number of beds. An improvement in the epidemiological situation would be indicated by a decrease in the number of ICU patients and a decrease in the number of hospitals with maximum occupancy of such units.

4. Indicators of the rapid spread of infection include *the proportion of patients hospitalized in relation to those identified.* This ratio clearly demonstrates the coverage of testing. When hospitalizations exceed 15-20% of new cases, the epidemic may be hidden by inadequate testing. This indicator should therefore also be used in a comprehensive assessment of the epidemiological situation.

5. The criterion for a sufficient number of tests should be *a positive rate in public laboratory centers*. A positive rate of no more than 20% should be achieved. For this purpose, the testing protocol should be changed and, instead of the proposed self-isolation, contact persons without signs of ARI should be tested to identify patients. The current situation in public centers is such that most of them test positive in the range of 50%, which completely rules out controlling the spread of the pandemic. From an economic point of view, unnecessary testing would cost the state considerably less than hospital treatment. In methodology calculations, only PCR testing, which takes into account new cases, should be taken into account, excluding antigen testing as less reliable (formulae (4) -(5)).

The use of the additional indicators mentioned above, which improve analysis of the situation of coronavirus infection, would allow a more rapid response to introduce SARS-CoV-2 control measures and significantly reduce the number of additional hospital admissions and the burden on national and local budgets.

The authors believe that future multidisciplinary research should focus on environmental factors, the presence of region-specific chronic diseases, age structure, and their influence on the spread and course of infectious diseases (caused by factors other than SARS-CoV-2). The decision-making system for the implementation of restrictions should also consider the regional specificities and economic consequences of quarantine restrictions, which in the medium term can significantly degrade the quality of life and health. Such a bio-economic approach in the research and decision-making system for the application of quarantine restrictions would address the challenges of enhancing biosecurity and economic sustainability in a comprehensive manner.

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Received 26.01.22.
Reviewed 01.02.22.igned for print 03.08.2022.

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ВДОСКОНАЛЕННЯ СИСТЕМИ ІНДИКАТОРІВ ДЛЯ ОЦІНКИ ЕПІДЕМІОЛОГІЧНОЇ СИТУАЦІЇ ТА ПОСИЛЕННЯ ОБМЕЖУВАЛЬНИХ ЗАХОДІВ В УМОВАХ АДАПТИВНОГО КАРАНТИНУ, ВИКЛИКАНОГО ПОШИРЕННЯМ COVID-19

Розглянуто проблему ефективності реагування держави на виклики для системи охорони здоров'я, що обумовлені поширенням інфекції, викликаної SARS-CoV-2. Проведено аналіз міжнародних економічних досліджень, що стосуються впливу на соціально-економічну систему загалом та систему охорони

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здоров'я зокрема. Виявлено, що переважно вони розглядають вплив різноманітних факторів на поширення коронавірусу чи його наслідки для окремих сегментів або економічної системи загалом, реагування системи прийняття рішень на варіанти поширення інфекції або моделюють різні сценарії на виклики перед системою охорони здоров'я. Проте в дослідженнях не розкрите питання, які критерії повинні застосовуватись при уведенні обмежувальних заходів або які зміни потрібно внести до системи оцінювання загроз для мінімізації навантаження на медичну систему. Тому автори проаналізували діючу національну систему індикаторів, що використовуються для визначення регіонів зі значним поширенням SARS-CoV-2. На основі ретроспективного аналізу попередніх хвиль поширення коронавірусу в Україні та уведення через це карантинних обмежень було встановлено, що прийняття рішення щодо посилення карантинних обмежень відбувалось зі значною затримкою. Це призводило до перенавантаження медичної системи та надлишкових госпіталізацій, яких можна було б уникнути при завчасному введенні карантину. Виявлено, які зміни в методиці оцінювання потрібно здійснити для вчасного посилення карантинних обмежень. Проведено оцінку заповнення лікарняного фонду за умови вчасного уведення карантину на прикладі м. Київ та вартості надлишкових госпіталізацій. Запропоновано зміни в діючій методиці оцінки регіонів зі значним поширенням SARS-CoV-2, які передбачають уведення додаткових показників та кількісні зміни для існуючих індикаторів.

Ключові слова: *карантинні заходи; пандемія; система прийняття рішень; рівень госпіталізації; ПЛР-тестування; перевантаженість лікарень*