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Analysis and modeling of the impact of restrictive measures on the development of the COVID-19 situation on the example of the Kaluga region

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Abstract. At the time of writing, humanity's struggle with coronavirus infection has been going on for almost 1.5 years, but the outcome is still unknown. The SARS-CoV-2 virus significantly affects the life of every person, which underlines the urgency of the problem. To combat COVID-19, the authorities of the region take many decisions to delay and slow down the growth of morbidity. This article is aimed at studying the impact of restrictive measures imposed by the authorities on the development of the situation with a new coronavirus infection. A computer prognostic model will be used to compare the effectiveness of each solution for new virus strains and outbreaks of morbidity. Based on the model, the results of the impact of decisions and methods taken by the authorities during the pandemic on the development of the morbidity situation will be analyzed. In order to obtain statistically important data on territorial parameters, the Kaluga region was chosen, taking into account the location near Moscow, where the disease manifests itself most vividly, due to the large number of residents.

1 Introduction

At the beginning of the coronavirus pandemic in February-March 2020, the authorities of different countries did not have a clear understanding of how to behave in new, previously unknown conditions. Due to the high social tension and collective fear of a new disease, it was decided to introduce restrictive measures of various kinds in the Russian Federation as a whole and in certain regions. An example for the initial stage of restrictive measures was the situation with attempts to contain the outbreak of viral infection in the People's Republic of China (PRC).

Thus, the purpose of this article is to study the effect of the introduction of restrictive measures: the introduction of universal lockdown, the introduction of distance learning in general education organizations, educational organizations of professional and higher education, the introduction of a mask regime and mandatory social distancing. As well as

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their impact on minimizing the incidence of a new coronavirus infection on the example of the situation in the Kaluga region.

The study was conducted using simulation technology. Modeling allows you to create a virtual environment in which it is possible to safely verify theoretical calculations and predict different outcomes of the same situation, as well as analyze the influence of various factors on a certain event in the past, present and future.

2 Research methodology

The research software package includes AnyLogic software from the Russian company The AnyLogic Company. This application includes a well-developed graphical interface for convenient construction of a computer model using Drag-n-Drop technology. Also, AnyLogic was created based on the Java language and is supported by it in the project even by the user, which allows more experienced developers to additionally process the analysis results.

When studying the impact of restrictive measures imposed by the authorities on the development of the situation with the new coronavirus infection COVID-19, a free version of the application was used: AnyLogic Personal Learning Edition. This version has all the necessary tools for building a model and its further processing.

The model of the impact of restrictive measures on the development and spread of COVID-19 should take into account many factors and parameters. Statistically important information includes the types of measures and methods of combating coronavirus infection and the results of research on this problem in the field of medicine. The reaction to the emergence of new strains of viruses and the rise of a new wave of infected was also taken into account. Based on these factors, a predictive model is constructed, the analysis of which is presented in this article.

The tools that were used to create the above model:

• Parameters are fields that store and transmit values:

A. General parameters, including general information about the course of coronavirus infection:

- TotalPopulation – the population of the Kaluga region at the time of writing. Is a constant integer equal to 1000980 [1].
- StartInfectoiusPeople – the number of infected people who started intensive infection of the entire population. Is a constant integer equal to 10.
- Infectivity – the overall probability of getting a coronavirus infection. It is a floating point number that can vary from 0.1 to 1, where the left border is the minimum chance of infection, and the right border is the maximum [2].
- AverageIncubationTime – the duration of the incubation period in days during which the disease develops in the human body (do not relate to the clearly infected). Is a constant integer equal to 11 [3].
- AverageIllnessDuration – the duration of the COVID-19 disease in days for which the human body is fighting the virus. Is a constant integer equal to 25 [4].
- ProcessCure - effectiveness of medicine: methods of treatment, improvement of prescription drugs, study of strains of coronavirus infection. It is a floating point number that can vary from 0.1 to 1, where the left border is the minimum chance of successful treatment of the patient, and the right border is the maximum [5].
- DeathProbability – the probability of death of a person infected with the SARS-CoV-2 virus. It is a floating-point number that can vary from 0.001 to 0.09, where the left border is the minimum chance of death, and the right border is the maximum [6].
- WithoutCopulaProbability – the probability of the body not to produce antibodies after a positive result of treatment for coronavirus. Is a constant floating point number equal to 0.15.

B. Vaccination rating parameters - describe the impact of vaccination on the development of the virus:
- IsReadyVaccine is an indicator of the readiness of effective vaccination against coronavirus infection. Takes the value 0 or 1, depending on the refusal or readiness of vaccination, respectively.
- Vaccination – the probability of a successful course of treatment with a vaccine in which antibodies are produced in the body. Is a constant floating point number equal to 0.91.
- VaccineVoluntaryProbability – the probability of voluntary vaccination of the population. Is a constant fractional number equal to 0.04.
- VaccineForcedProbability – the probability of vaccination of the population, mandatory conditions and government measures are used. Is a constant fractional number equal to 0.14.

C. Parameters of the rating of hygiene products in public places:
- ContactInfectiousRate – coefficient of physical interaction between residents, population density coefficient. It is a floating point number that can vary from 0.1 to 1, where the left border is the minimum of interaction between residents of the region, and the right border is the maximum.
- UseSterileGlovesRate – the coefficient of use of sterile disposable gloves when visiting crowded places. It is a fractional number that can vary from 0.1 to 1, where the left border is the full approval of the residents of the region to use gloves, and the right border is a refusal.
- WearMaskRate – the coefficient of use of masks (disposable, reusable fabric masks, masks with a filter, etc.) when visiting crowded places. It is a fractional number that can vary from 0.1 to 1, where the left border is the full approval of the residents of the region to use masks, and the right border is a refusal.

D. Parameters of the rating of public events:
- SmallEventRate - the coefficient of holding events with up to 100 participants. It is a floating-point number from 0.1 to 1, where the left border is a complete ban on events of this level, and the right border is a complete approval.
- MiddleEventRate - the coefficient of holding events with the number of participants from 101 to 800 people. It is a floating-point number from 0.1 to 1, where the left border is a complete ban on events of this level, and the right border is a complete approval.
- BigEventRate - the coefficient of holding events with the number of participants from 801 people. Is a floating-point number from 0.1 to 1, where the left border is a complete ban on activities of this level, and the right border is a complete approval.

E. Parameters of the rating of remote activities:
- TeleworkFullRate - coefficient of the full remote format of work/study for all possible spheres of human activity. It is a floating-point number from 0.1 to 1, where the left border is a complete transition to remote activity, and the right border is the absence of a remote format.
- TeleworkPartialRate - the coefficient of partial remote activity, at which the conditions for the department's transition to a remote format are determined. It is a floating point number from 0.1 to 1, where the left border is compliance with the conditions for switching to a remote format, and the right border is the absence of a remote format.
- Events are a set of conditions, when true, the parameters change their value to a new one.

A. Waves - the amplitude of the spread of coronavirus infection
- FirstWave - describes the first surge in the development of the pandemic, which occurred during the period from March 12, 2020 to May 11, 2020. Parameters when this event occurs: ContactInfectiousRate = 0.6; WearMaskRate = 0.5; UseSterileGlovesRate = 0.7; SmallEventRate = 0.5; MiddleEventRate = 0.4; BigEventRate = 0.4; TeleworkFullRate = 0.5; TeleworkPartialRate = 1; Infectivity = 0.5; DeathProbability = 0.02.
- FirstFall - describes the first decline in the spread of the virus, which occurred between May 12, 2020 and August 18, 2020. Parameters when this event occurs: ContactInfectiousRate =

0.2; WearMaskRate = 0.2; UseSterileGlovesRate = 0.4; SmallEventRate = 0.1; MiddleEventRate = 0.1; BigEventRate = 0.1; TeleworkFullRate = 0.1; TeleworkPartialRate = 0.1; Infectivity = 0.25; DeathProbability = 0.01.

- SecondWave – the second rise in the level of virus spread in the period from August 19, 2020 to December 24, 2020. The parameters took the following value: ContactInfectiousRate = 0.8; WearMaskRate = 0.2; UseSterileGlovesRate = 0.9; SmallEventRate = 0.6; MiddleEventRate = 0.3; BigEventRate = 0.2; TeleworkFullRate = 0.8; TeleworkPartialRate = 0.5; Infectivity = 0.4; DeathProbability = 0.02.
- SecondFall – the second decline in the development of coronavirus infection in the period from December 25, 2020 to May 25, 2021. The parameters took the following value: ContactInfectiousRate = 0.5; WearMaskRate = 0.3; UseSterileGlovesRate = 0.8; SmallEventRate = 0.3; MiddleEventRate = 0.2; BigEventRate = 0.1; TeleworkFullRate = 0.8; TeleworkPartialRate = 0.1; Infectivity = 0.4; DeathProbability = 0.008.
- ThirdWave – the third wave of the COVID-19 surge in the period from May 26, 2021 to July 10, 2021. The parameters took the following values: ContactInfectiousRate = 0.8; WearMaskRate = 0.3; UseSterileGlovesRate = 0.7; SmallEventRate = 0.6; MiddleEventRate = 0.3; BigEventRate = 0.2; TeleworkFullRate = 0.8; TeleworkPartialRate = 0.5; Infectivity = 0.4; DeathProbability = 0.02.
- ThirdFall – the last known, at the time of writing, decline in coronavirus infection occurred in the period from July 11, 2021 to September 14, 2021. The parameters took the following value: ContactInfectiousRate = 0.5; WearMaskRate = 0.3; UseSterileGlovesRate = 0.8; SmallEventRate = 0.3; MiddleEventRate = 0.2; BigEventRate = 0.1; TeleworkFullRate = 0.8; TeleworkPartialRate = 0.1; Infectivity = 0.4; DeathProbability = 0.009.
- FutureWave – an unknown future period in which the SARS-CoV-2 virus will again begin to spread effectively among the population. The parameters were regulated as a study, based on known methods of combating coronavirus.
- FutureFall – an unknown upcoming period in which the spread of COVID-19 will begin to decline. The parameters changed during the study, different reactions of the authorities to the development of the pandemic were taken.

B. CureEffectiviness — effectiveness of COVID-19 treatment:

- EarlyStadyCure - early methods and methods of combating such a virus. The key parameter is ProcessCure equal to 0.08
- ProperCure - medicine has learned to fight coronavirus, the probability of successful recovery of patients has increased. ProcessCure increased to 0.3.

C. VaccineCreate - the process of creating a vaccine and further vaccination of the population:

- Process - the vaccine is being manufactured, scientists are conducting experiments. The IsReadyVaccine parameter takes the value 0.
- Done - an effective vaccine is ready for use among the population of the Kaluga region. The IsReadyVaccine parameter takes the value 1.
- Drives are some containers with contents that are exchanged with each other using streams:

A. Suspicious – people who have not yet been affected by the disease. Initial value: TotalPopulation-StartInfectiousPeople.

B. Exposed – people who may be potentially infected (have been in contact with coronavirus patients).

C. Infectious – people who have contracted COVID-19 and are carriers of the virus. Initial value: StartInfectiousPeople.

D. Cured – people who have been successfully treated in hospitals.

E. Recovered – healthy people whose body has developed antibodies to fight coronavirus.

F. Vaccinated – people who have been treated with a vaccine.

• Streams - transfer data from one drive to another:

A. VaccineProcess - the Suspicious drive transfers data to the Vaccined drive. Flow formula: isReadyVaccine * Susceptible * Vaccination * (VaccineVoluntaryProbability + VaccineForcedProbability).

B. ExposedRate - The Suspicious drive transmits data to the Exposed drive. Flow formula: ContactInfectiousRate * (WearMaskRate + UseSterileGlovesRate) / 2 * (SmallEventRate + MiddleEventRate + BigEventRate) / 3 * (TeleworkFullRate + TeleworkPartialRate) / 2 * Infectious * Infectivity * Susceptible / TotalPopulation.

C. InfectiousRate - The Exposed drive transmits data to the Infectious drive. Flow formula: Exposed / AverageIncubationTime.

D. RecoveredRate - the Infectious drive transmits data to the Cured drive. Flow formula: Infectious * ProcessCure / AverageIllnessDuration.

E. DeadRate - The Infectious drive transmits data to the Dead drive. Flow formula: Infectious * DeathProbability / AverageIllnessDuration.

F. RecoveredProcess - The Cured drive transmits data to the Recovered drive. The flow formula is Cured.

G. WithoutCopula - the Cured drive transmits data to the Suspicious drive. Flow formula: Cured*WithoutCopulaProbability.

• A timeline describing the number of infected and deceased per day.

A graphical representation of the described model is shown in Fig. 1.

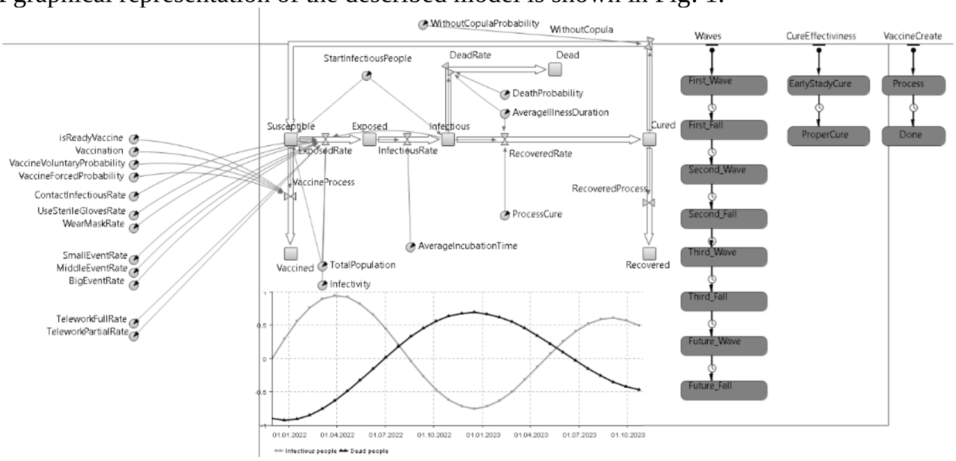

Fig. 1. Computer model: the impact of restrictive measures imposed by the authorities on the development of the situation with the new coronavirus infection Covid-19.

3 Results of the study

The Kaluga Region was chosen to study the impact of restrictive measures. The peculiarity of the region is its proximity to Moscow, the capital of Russia and the largest city in the country. Thus, a large passenger, transport and cargo flow passes through this subject of the state, which undoubtedly critically affects the number of contacts between people and, as a result, the number of infections. In addition, proximity to Moscow affects the restrictive measures introduced – due to the similarity of the morbidity situation, the regional government partially or completely adopts the experience of the authorities of the capital, thus, it is possible to obtain approximate data on the effectiveness of these measures in the subject of the Russian Federation with the largest number of cases of new coronavirus infection.

Information and statistics on the number of diseases for the development of the model were imported from a Yandex project called Yandex.Datalense, as well as from data from the Johns Hopkins University Coronavirus Statistics study.

Fig. 2 shows the situation of the development of coronavirus infection in the Kaluga region in the form in which it is currently occurring.

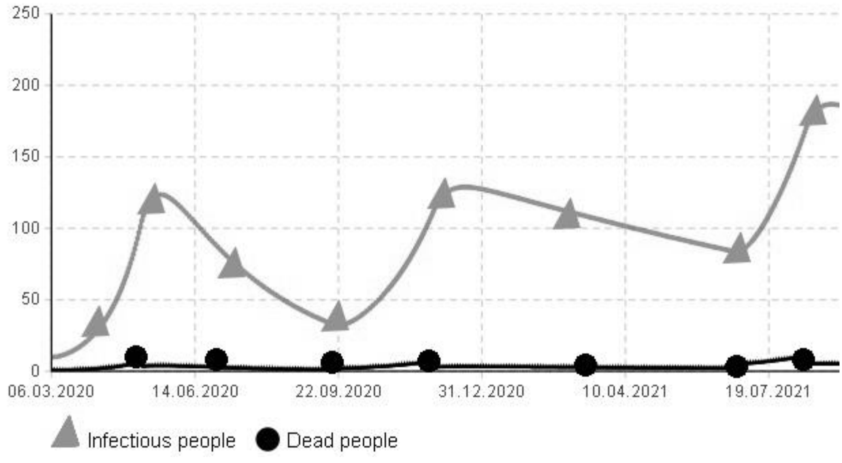

Fig. 2. Current development of coronavirus infection in the Kaluga region.

The first criterion of restrictive measures introduced by the Russian authorities was a general lockdown, which is a ban on the operation of shopping and entertainment centers, catering establishments, restaurants and bars, as well as other leisure establishments. In addition, a period of self-isolation was introduced, during which the authorities recommended not to leave the place of residence, except in cases of forced grocery shopping, pet walking and garbage disposal. Fig. 3 shows the situation of the development of coronavirus infection if a general lockdown had not been introduced, while other restrictive measures were introduced to the same extent.

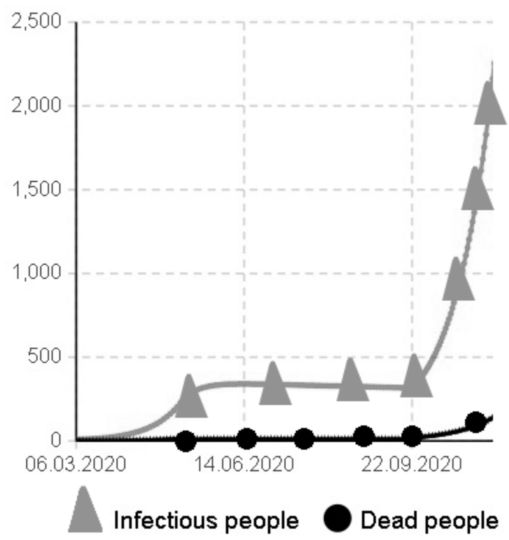

Fig. 3. Simulation of events in the absence of a lockdown in the first stages of a pandemic.

The next step in the fight against the spread of coronavirus infection was the introduction of training in educational organizations using remote digital educational technologies and the mandatory (taking into account the capabilities of the enterprise) transfer of employees of enterprises of various fields of activity and forms of ownership to remote work. Various training platforms have been used for training (for example, Yandex.Class, Google.Class and the like), video communication applications (Zoom, Skype, Teams), while a large load fell on the Network City system. Education", with the help of which the functionality of an electronic journal and diary, an electronic duplicate of the schedule of classes, as well as means of communication between the teacher and the student is implemented.

The main purpose of distance learning was to minimize direct physical contacts between students, teachers and employees of educational organizations. However, many students, as well as legal representatives of underage students, were dissatisfied with the introduction of this restrictive measure due to a decrease in the quality of education and the lack of opportunities for socialization of children and adolescents in a familiar environment. Remote work also contributed to a decrease in the number of contacts between colleagues, but in turn, in this area, most employees were satisfied with the measures taken.

In Fig. 4, one can observe a model of the development of the situation of the spread of coronavirus infection if schoolchildren and students continued to attend educational institutions and did not switch to education using remote digital platforms, and absolutely all employees continued to work in the usual full-time mode.

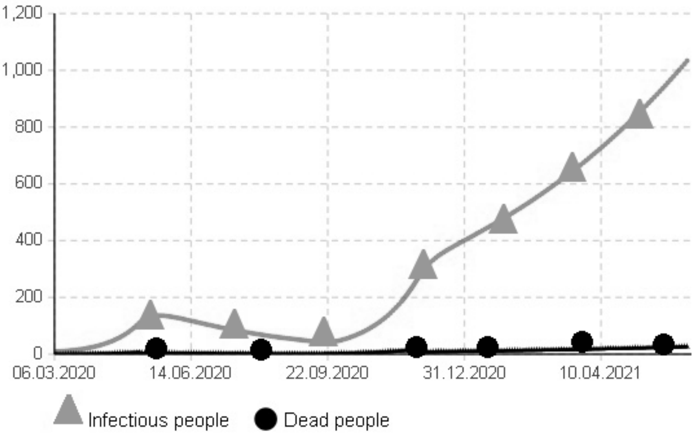

Fig. 4. Simulation of events in the absence of remote activity during a pandemic.

Further restrictions affected mass events such as concerts, festivals, forums, competitive and gaming programs for people of all ages. The introduction of these measures has negatively affected many areas of public and social life. However, this allowed breaking the chain of contacts between the visitors of these events, reducing the number of communications to reduce morbidity. At the same time, at various stages of lifting restrictions, the authorities allowed mass events of various attendance:

• small - up to 100 people;
* average – up to 500 people;
* large – more than 500 people.

At the peak of the first wave of the epidemic, a ban was imposed on all mass events, regardless of the number of visitors, then in the process of stabilizing the situation, restrictions were relaxed. This growth is shown in Fig. 5

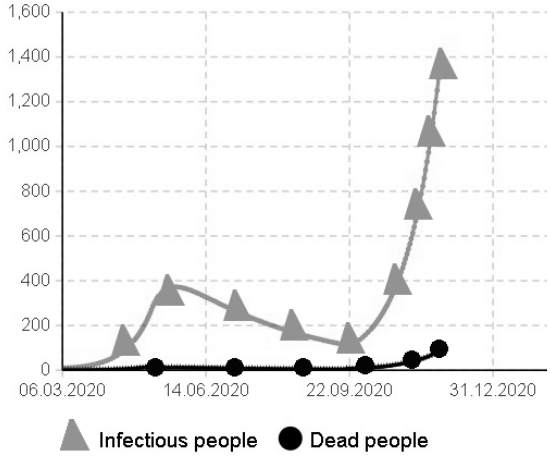

Fig. 5. Simulation of events when approving activities during a pandemic.

It has also become mandatory to wear masks and gloves in public to prevent the spread of the virus through contact surfaces (for example, bus handrails, elevator buttons, store counters, etc.). Various studies evaluate the effectiveness of the mask-glove regime differently, but Fig. 6 shows how the rates of morbidity would change in the absence of legally fixed mandatory wearing of personal protective equipment.

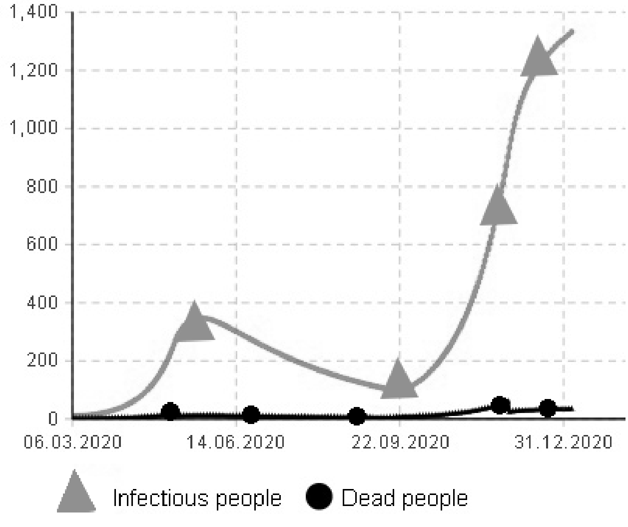

Fig. 6. Simulation of events with complete disregard of the mask mode during a pandemic.

4 Discussion of the results

Based on the graphs presented in the figures, a noticeable and natural trend can be clearly traced - each of the restrictions imposed by the authorities contributed to a certain extent to the reduction of morbidity, not a single restriction was introduced thoughtlessly and aimlessly.

To compare the effectiveness of the restrictions imposed, it is necessary to compare the number of cases on a certain date. The higher the number– the more effective one or another method of containing infection is, since in the absence of the measure in question, the incidence would increase higher than in the absence of another measure, therefore, the impact is higher.

For an example of consideration, let's take the date 14.06.2021, presented on all charts.
With the introduction of all measures to contain the spread of coronavirus infection, the incidence in the Kaluga region does not exceed 100 people per day.
In the absence of a lockdown, the daily incidence will be about 250-300 people.
If distance learning and remote work had not been introduced, the incidence would have been about 120-130 people per day.

In the absence of a ban on mass events, the daily incidence would be about 350-370 people.
In the absence of legislative consolidation of the mandatory wearing of masks and gloves, the incidence of coronavirus infection would be approximately 300 people per day.

Let's make a ranking of the described restrictive measures in accordance with the above criterion:
- Ban on holding mass events.
- Mandatory wearing of personal protective equipment.
- Universal lockdown.
- Distance learning and remote work.

Thus, based on the available data, the following conclusions can be drawn:
- The most effective means of containing a new coronavirus infection is a ban on holding mass events.
- The regularity of the effectiveness of this measure is obvious - the largest accumulation of a large number of people in a confined space, often supplemented by poor ventilation of event rooms, contributes to the fastest spread of the virus by airborne droplets and contact routes.
- The next most effective is wearing masks and gloves.
- This method involves the creation of a barrier between the respiratory organs / skin and the environment, so an already infected person does not have the opportunity to further spread virus particles and infect others.
- The third most effective restrictive measure is the introduction of a lockdown.
- The number of contacts when visiting public places is large, but people are at a greater distance than when attending mass events, so the infection rate decreases, and this measure is less effective.
- The least effective method is the introduction of a distance learning and work format.
- Children and adolescents are less susceptible to coronavirus infection, so the effectiveness of this measure is low for students of educational organizations.
- Contact work of students and teachers is not the most common form of work, therefore, for students of professional educational organizations and educational institutions of higher education, it also did not become effective enough.
- In the work environment, colleagues are in contact, but the volume of tasks associated with direct close contact between people is low.
- Employees of those fields of activity that involve working with computers were mainly transferred to a remote work format, and employees whose activities are directly related to contacts, communication and other similar activities continued to perform their functions in person, which explains the low effectiveness of this method of containing the spread of infection.

5 Conclusion

Taking into account all factors affecting coronavirus infection, this model can be considered fair and correct, since it takes into account most of them. However, it is important to remember that there are factors that humanity cannot track and take into account - the influence of natural and climatic effects. These include, for example, increased morbidity in the cold season, differences in contacts between people at different times of the year (in summer, most people spend more time outdoors, travel, thus increasing contact and the likelihood of infection).

It is necessary to take into account the psychological and cultural characteristics of different peoples. The Russian Federation is a multinational country, and a large number of nationalities live in the Kaluga Region, whose traditions may include customs that contradict the restrictive measures imposed (for example, it is customary for Russians to shake hands when meeting men, and for Georgians it is customary to hug and kiss a friend they meet).

Thus, the average indicators were taken as a basis without taking into account factors that cannot be quantified quantitatively.

Summing up, we can draw the following conclusion: the model presented in the article can be used to predict the further development of coronavirus infection, taking into account changing factors – for example, stricter control over the wearing of masks will increase the effectiveness of the mask regime as a whole. In addition, the analyzed factors and their impact on the development of the virus can be used as visual materials to demonstrate the effectiveness of restrictive measures and increase awareness of citizens, since it is on their consciousness that the future fate of humanity and the extent of the negative impact of the coronavirus on our habitual daily life most depend.

References

1. A. Tkachenko, D. Lavrentev and M. Denisenko, Development of a simulation model for the spread of COVID-19 coronavirus infection in Kaluga region, E3S Web of Conferences, Vol. 270 01003 (2021) https://doi.org/10.1051/e3sconf/202127001003
2. R. Maclntyre, Q. Wang, The Lancet Infectious Diseases (2020)
3. Y. E. Gagarin, U. V. Nikitenko, M. A. Stepovich, J. of Physics: Conference Series: Current Problems, 012106 (2021) DOI 10.1088/1742-6596/1902/1/012106
4. D.K. Nekrasov, M.A. Kuznetsova, K.D. Andreeva, FORCIPE, S (2020)
5. T.N. Bilichenko, Academy of Medicine and Sports, **2** (2020)
6. R. Verity, L.C. Okell, I. Dorigatti, P. Winskill, C. Whit-taker, N. Imai, The Lancet Infectious Diseases (2020)
7. G.G. Onishchenko, T.E. Sizikova, V.N. Lebedev, S.V. Borisevich, BIOpreparaty. Prevention, diagnosis, and treatment, **4** (2020)
8. Resolution of the Government of the Kaluga Region of March 17 (2020)
9. N.G. Kondrashova, Audit and financial analysis **4**, 113 (2020)
10. A.L. Tkachenko, Information technologies in economics, business and management. Materials of the V International Scientific and Practical Conference, 194 (2018)
11. V. Boev, J. of Applied Informatics **6(30)**, 69 (2010)
12. A.V. Blagov, Modern Applied Science **9(4)**, 254 (2015)
13. S.C. Parks, M. Garifullin, R. Dronzek, Proceedings - Winter Simulation Conference, 1038 (2005)
14. A.S. Akopov, L.A. Beklaryan, Knowledge-Based Systems **174**, 103 (2019)
15. A.M. Rudenko, V.I. Rodionova, V.N. Stepanova, Advances in Intelligent Systems and Computing **726**, 1144 (2019)
16. V.S. Stepanov, Health Risk Analysis **4**, 12 (2020) 9 E3S Web of Conferences 270, 01003 (2021) WFCES 2021. https://doi.org/10.1051/e3sconf/202127001003
17. S. Marino, D.E. Kirschner, J. Theor. Biol. **227(4)**, 463 (2004)

18. A.G. Bareysha, Int. Scientific Research J. **1-4(20)**, 153 (2014)
19. F.M.G. Magpantay, N. Kosovalić, J. Wu, SIAM J. on Numerical Analysis **52(2)**, 735 (2014)
20. A. Godio, F. Pace, A. Vergnano, Int. J. Environ. Res. & Public Health **17(10)**, 3535 (2020)