Attitudes to Vaccination: How the Opinion Dynamics Affects the Influenza Epidemic Process

Suriya Kumacheva* Ekaterina Zhitkova* Galina Tomilina**

*St.Petersburg State University,
**EPAM System Inc.

Modelling and Simulation of Social-Behavioural Phenomena in Creative Societies (MSBC-2022)

September 23, 2022

General Ideas of Research

- it is assumed that there is a relation between the population's attitude to vaccination and the dynamics of the influenza epidemic;
- there are doubting agents in the population who make decisions about vaccination under the influence of others' opinions;
- it is assumed that the opinion dynamics are completed before the seasonal rising incidence starts, each agent has decided to vaccinate or not until this moment;
- then the epidemic rising, which is supposed to be described by modification of the classical Kermack-McKendrick model (1927), begins.

General idea of research – to verify a hypothesis about the influence of the opinion dynamics on the subsequent development of the epidemic process.

Why do we study influenza epidemic?

Reasons to Research the Influenza Epidemic

- One of the most widespread viruses in the world;
- Included in the top 10 most dangerous infections on the planet;
- On August 30, 2022, WHO announced an increased risk of resurgence of the influenza virus after the decline of the COVID-19 pandemic [https://www.who.int/];
- Numerous influenza vaccines have been developed in various laboratories around the world [Gao et al. 2007];
- Regular outbreaks of seasonal influenza in various countries of the world and ongoing vaccination have made it possible to collect extensive statistics [Erofeeva et al., 2021]

Basic scheme of research

Population

- A limited small population is considered (30 – 50 agents);
- Interpretation:
  - office
  - class at school
  - group of children in kindergarten

  and others
- The population is heterogeneous in terms of risk propensity, therefore, the population is heterogeneous in terms of attitude to vaccination
- Various scenarios of opinion dynamics

Attitude to vaccination

The difference in attitudes towards vaccination:

- extremely negative
- rational
- totally positive

Extremely negative attitude

[Briko et al., 2017, 2019], [Antonova et al., 2018], [Matz, 2013]:
Position A

- Medics and scientists;
- Those, who consider this particular type of vaccination to be ineffective;
- Those, who believe (often erroneously) that they or their relatives are immune to the disease;
- Those, who believe that a healthy lifestyle is enough without any vaccinations;
- Those, who have a negative experience of vaccination in the past (side effects, disease after vaccination, etc.);
- Others.

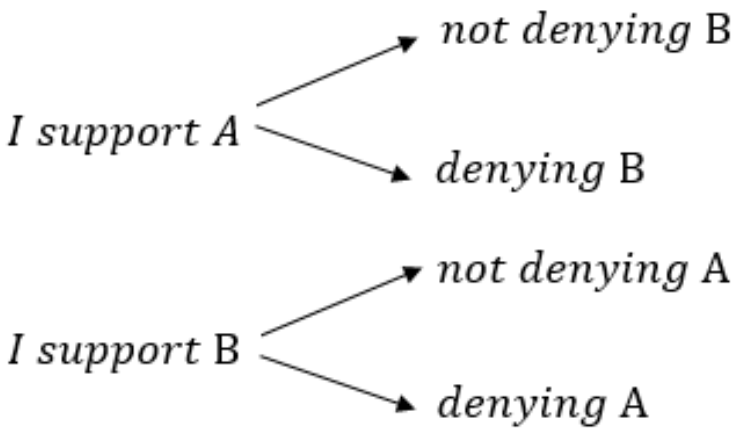
Totally positive attitude

Position B:

- Medics and scientists;
- Those who have benefited from vaccination in the past;
- Others.

Correction: rational attitude

In real life from the available opinions, the following combinations can be added:



- {Support A | denying B} – **anti-vaxxers**
- {Support B | denying A} – **pro-vaxxers**
- {Support A | not denying B} and {Support B | not denying B} – **rational attitude to vaccination**

Basic scheme of research

- Opinion dynamics
  - Network model
  - Simulations
  - Scenario analysis
- Epidemic process
  - Problem formulation
  - Parameters of the model
  - Simulations
  - Results
- Conclusions and prospects

Opinion Dynamics

Network Model: Initial State

- n agents of three types are considered:
  - anti-vaxxers;
  - pro-vaxxers;
  - undecided, rationally responding to available information.
- Three types of initial distributions of attitudes were considered:
  - 17% of pro-vaxxers, 65% of rational and 18% of anti-vaxxers (in accordance with the study of propensities to risk presented in [Niazashvili, 2007]);
  - 25% of pro-vaxxers, 65% of rational and 10% of anti-vaxxers (based on the assumption about Normal distribution of risk status);
  - 10% of pro-vaxxers, 65% of rational and 25% of anti-vaxxers (in accordance with the similar assumption).

Network Model: Representation of Network

- A studied population – a network $G = (N, P)$:
  - N is the set of agents;
  - P is a stochastic matrix of connections between agents;
- Configurations of the network:
  - random sparse graph;
  - random connected graph.

Network Model: Markov Process

- At the initial time moment: each agent i ($i = \overline{1, N}$) has his/her characteristics:
  - type (anti-, pro-, rational);
  - a certain belief f_i^0 which characterises his/her own attitude and decision (do not vaccinate / vaccinate);
- Various options for distributing agents of different types over the network are considered.
- The algorithm based on the Markov process [DeGroot, 1974] is used: not only connection between agents is indicated, but also its measure – the confidence degree of agents to each other (opinion weight);
- At each iteration, each agent i update the estimates f_i^t of their attitude based on the average estimates of the neighbors, taking into account the weights from the link matrix.

Network Model: Markov Process

Stopping condition: moment T, where

$$\sqrt{\sum_{t=1}^{T}(f_i^t - f_i^{t-1})^2} < 10^{-3}$$

or 10^3 iterations are reached.

After the process is stopped, the final strategies of the agents are determined; each agent makes the vaccination decision

- anti-vaxxers remain non-vaccinated regardless of their estimates;
- pro-vaxxers remain vaccinated regardless of their estimates;
- rational agents decide on a critical value – if their estimates is higher than it, they are vaccinated.

Numerical Simulation

Numerical Simulation: Visualisation of the Network

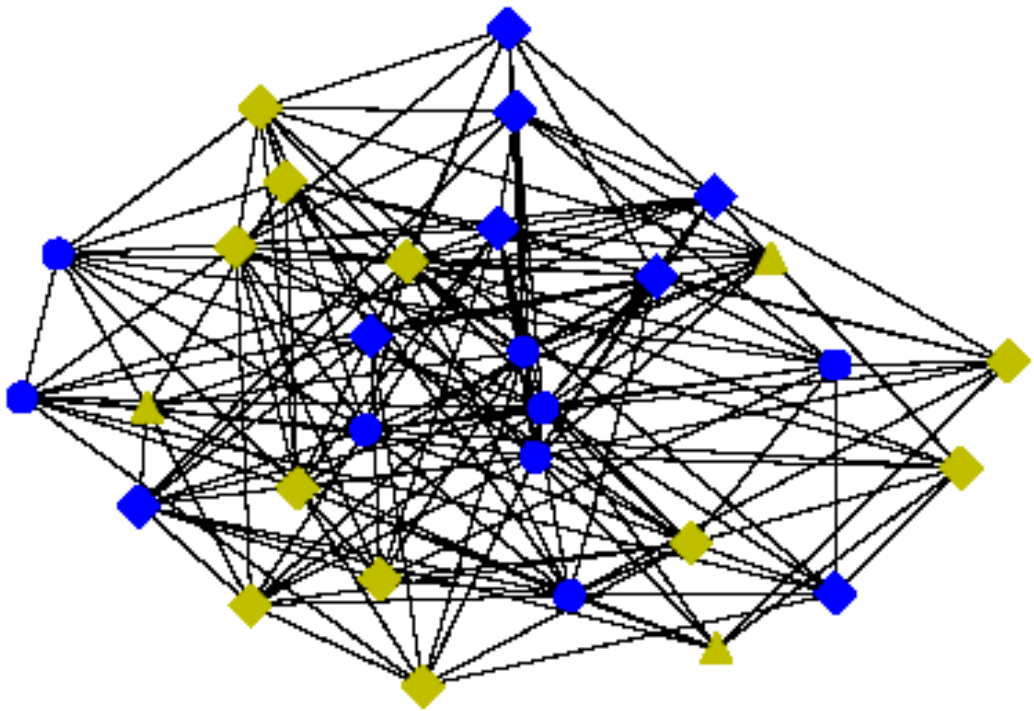
Agent characteristics:

- the propensity to vaccination – the forms of the nodes:
  - positive attitude – triangles △
  - neutral (rational) – squares □
  - negative attitude – circles ◯
- the agents' current decision on vaccination:
  - decided to vaccinate — yellow
  - decided not to vaccinate — blue

Example 1

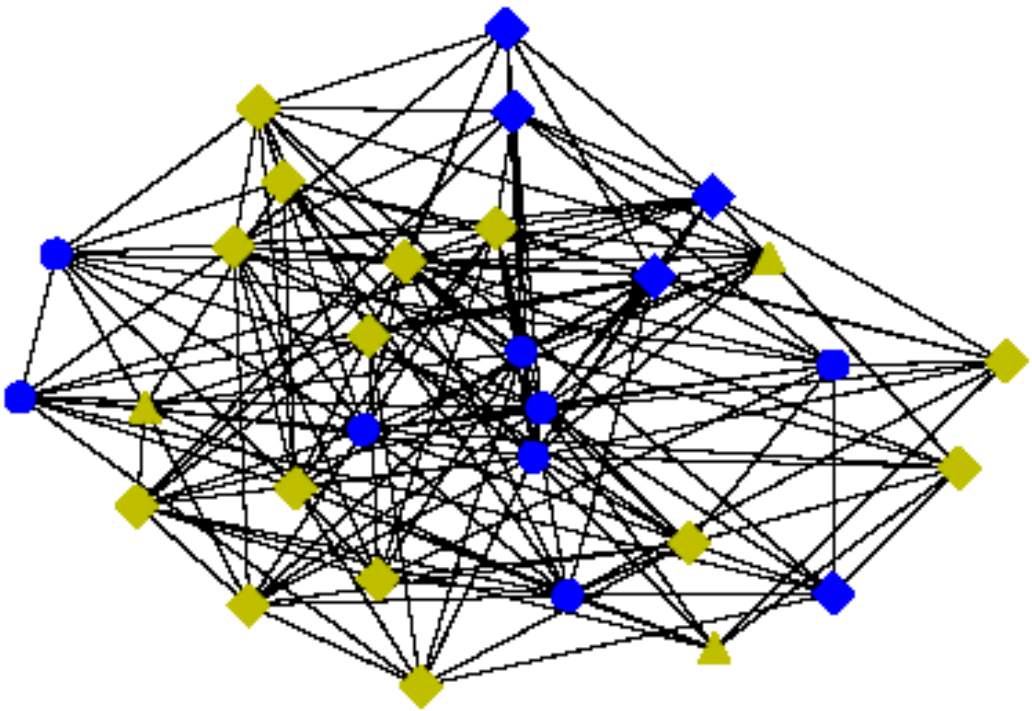
- The number of nodes: 30;
- Type of the network: random connected graph;
- Distribution of initial propensities (attitudes to vaccination): negative – 8, positive – 3, neutral – 19;
- Initially: going to vaccinate – 14, not going to vaccinate – 16;
- Process convergence: formally – 11 iterations, informally – 3 iterations;
- Finally: decided to get vaccination – 22, decided not to get vaccination – 8.

Example 1



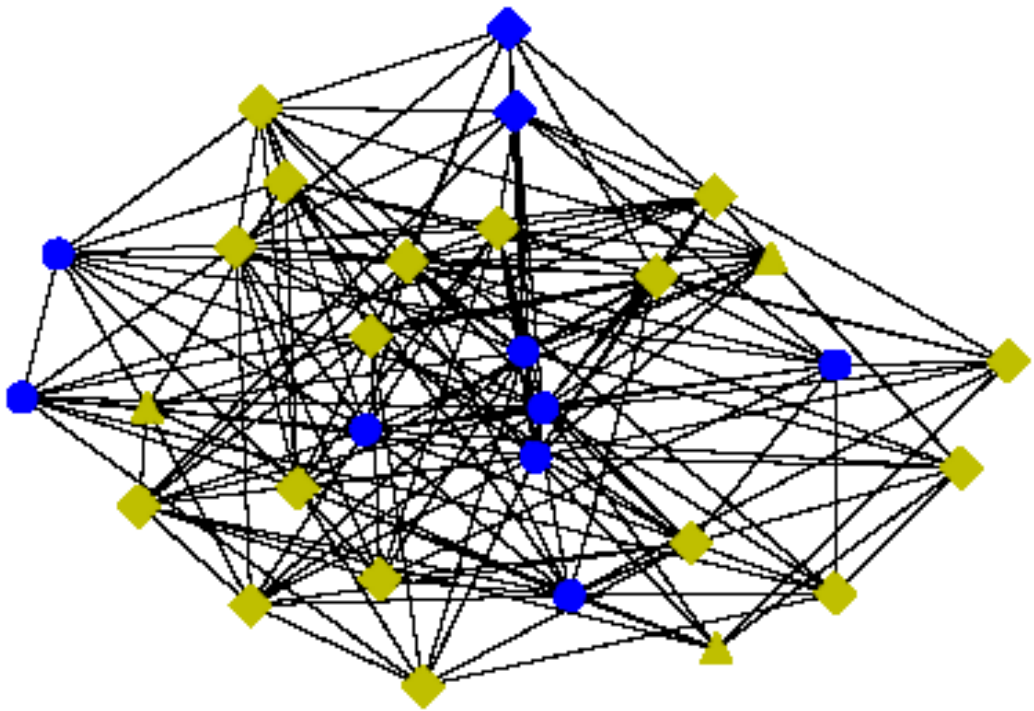
Example 1: Initial state of population, before opinion dynamics)

Example 1



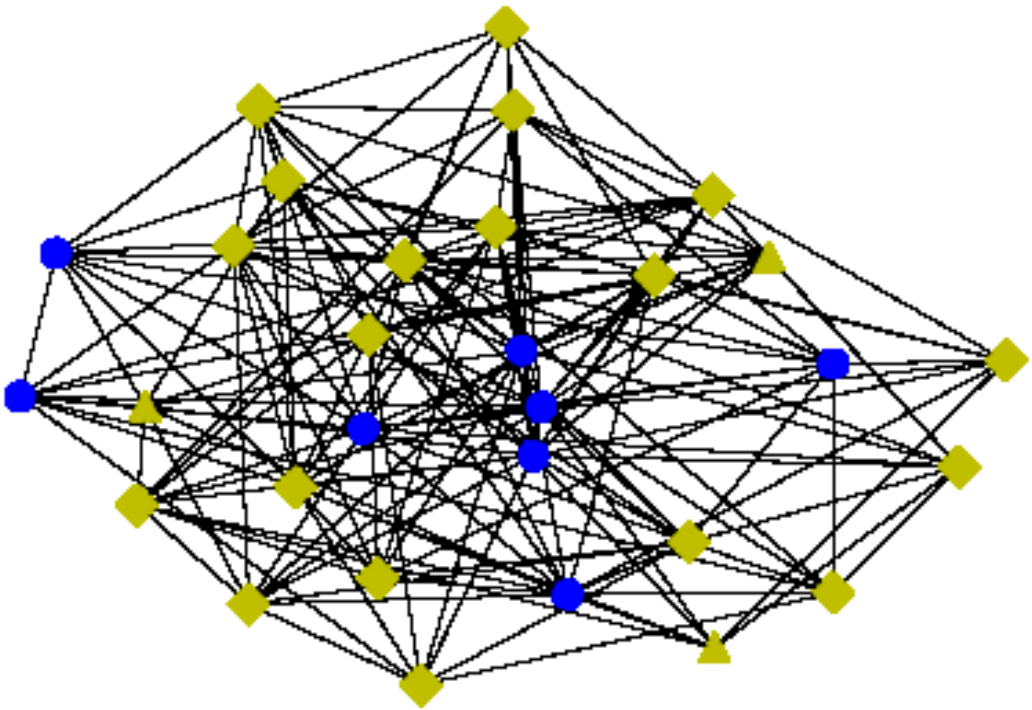
Example 1: Population after the first iteration

Example 1



Example 1: Population after the second iteration

Example 1



Example 1: The result opinion dynamics: final state of population after the third iteration

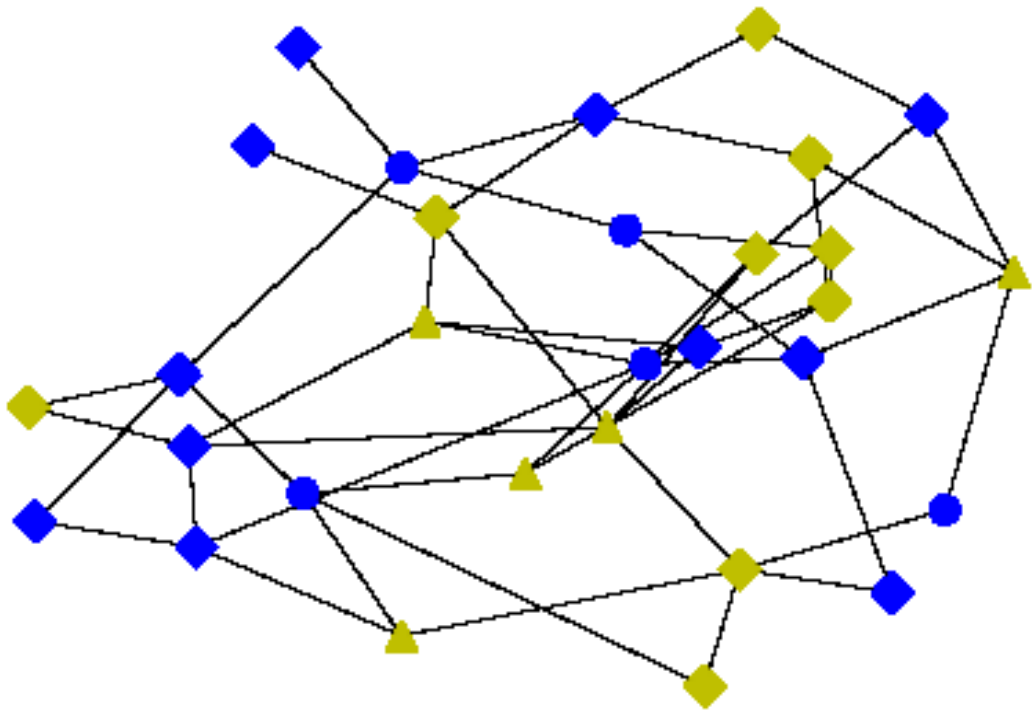
Example 1: Conclusions

- The case of positive dynamics: the number of those who are going to vaccinate increases and becomes bigger than the number of those who are not going to vaccinate;
- Possible reasons:
  - large number of agents with neutral attitude;
  - their location: throughout the network with a large number of connections;
- Final result: only persons with negative attitude will not vaccinate.

Example 2

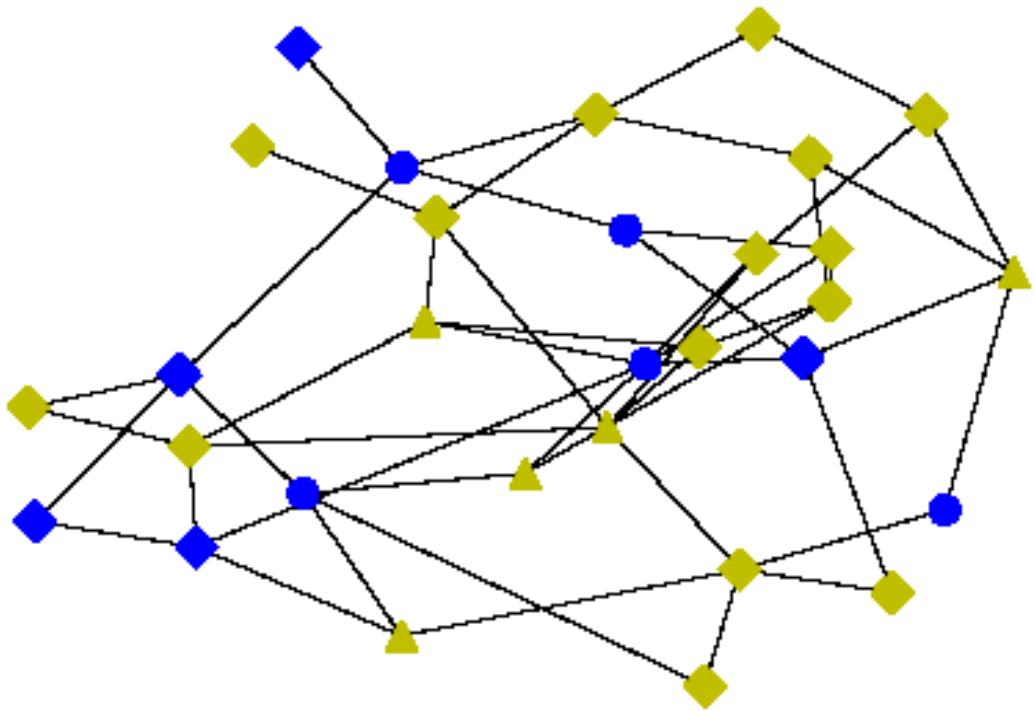
- The number of nodes: 30;
- Type of the network: random sparse graph;
- Distribution of initial propensities (attitudes to vaccination): negative – 5, positive – 5, neutral – 20;
- Initially: going to vaccinate – 14, not going to vaccinate – 16;
- Process convergence: formally – 43 iterations, informally – 3 iterations;
- Finally: decided to get vaccination – 25, decided not to get vaccination – 5.

Example 2



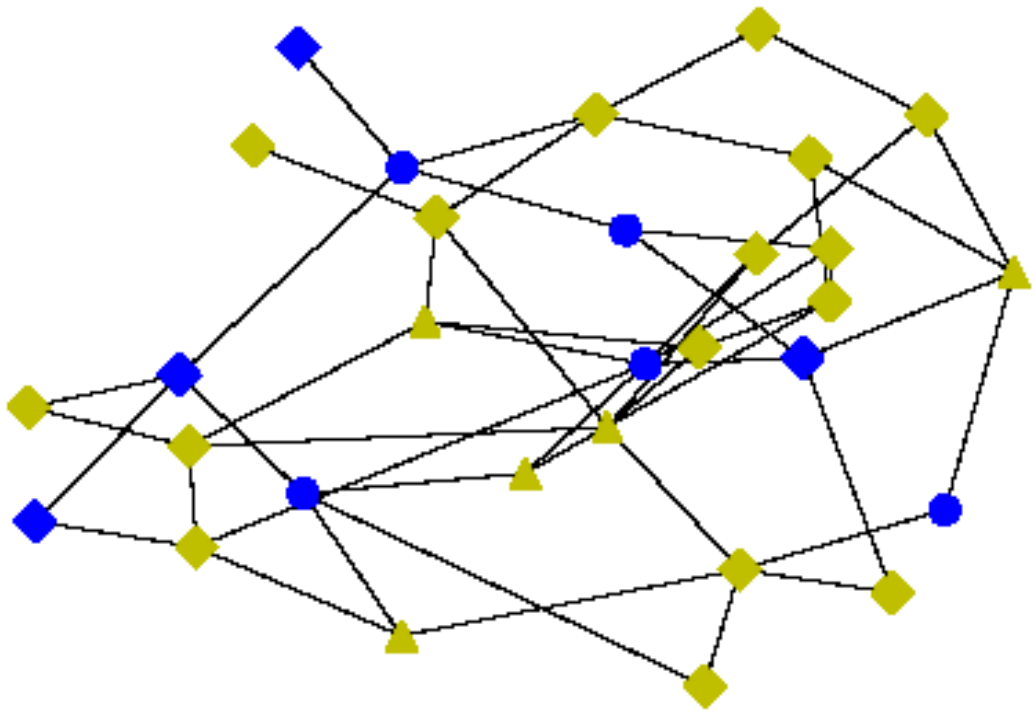
Example 2: Initial state of population, before opinion dynamics)

Example 2



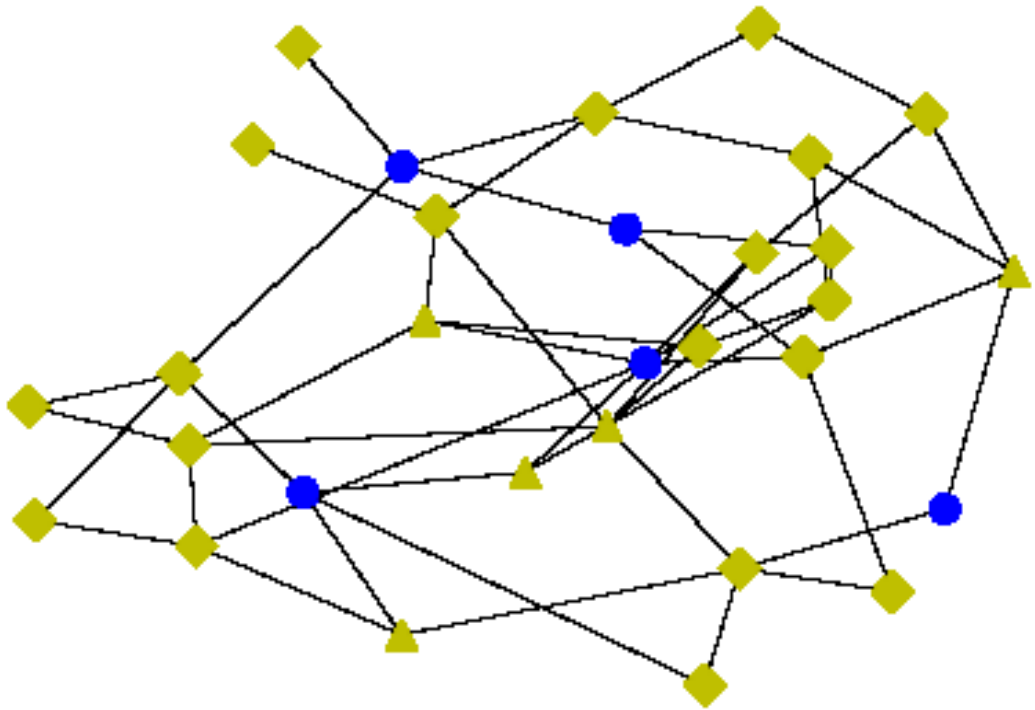
Example 2: Population after the first iteration

Example 2



Example 2: Population after the second iteration

Example 2



Example 2: The result opinion dynamics: final state of population after the third iteration

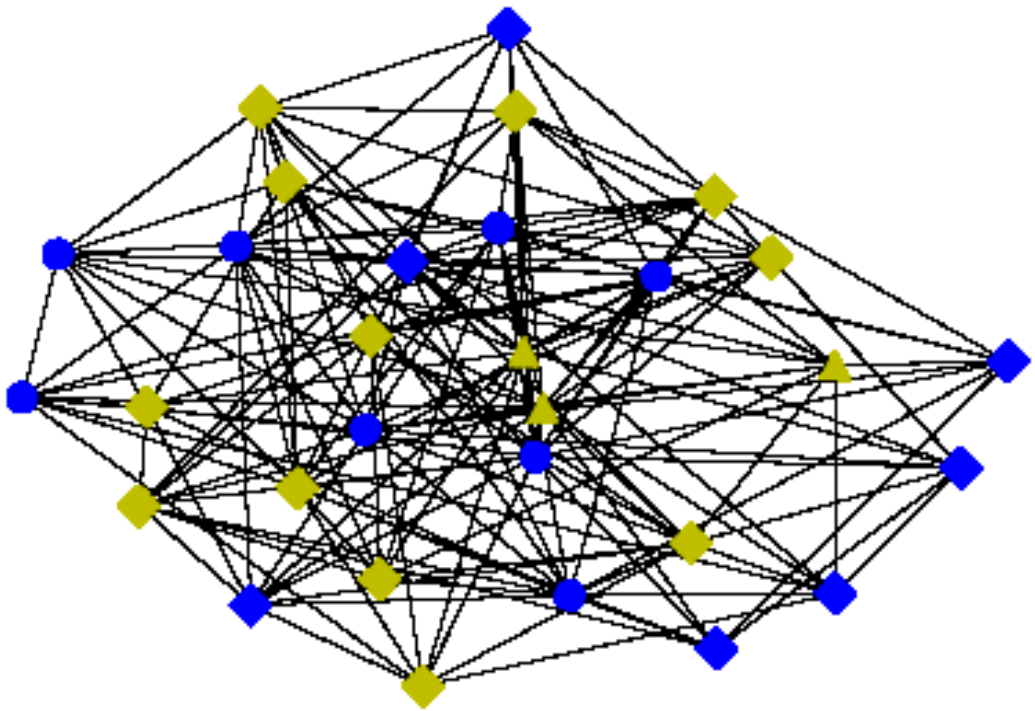
Example 2: Conclusions

- The case of positive dynamics: the number of those who are going to vaccinate increases and becomes bigger than the number of those who are not going to vaccinate;
- Possible reasons:
  - large number of agents with neutral attitude;
  - their location: throughout the network with a large number of connections;
  - the first agent who changed the opinion had a positive attitude;
- Final result: only persons with negative attitude will not vaccinate.

Example 3

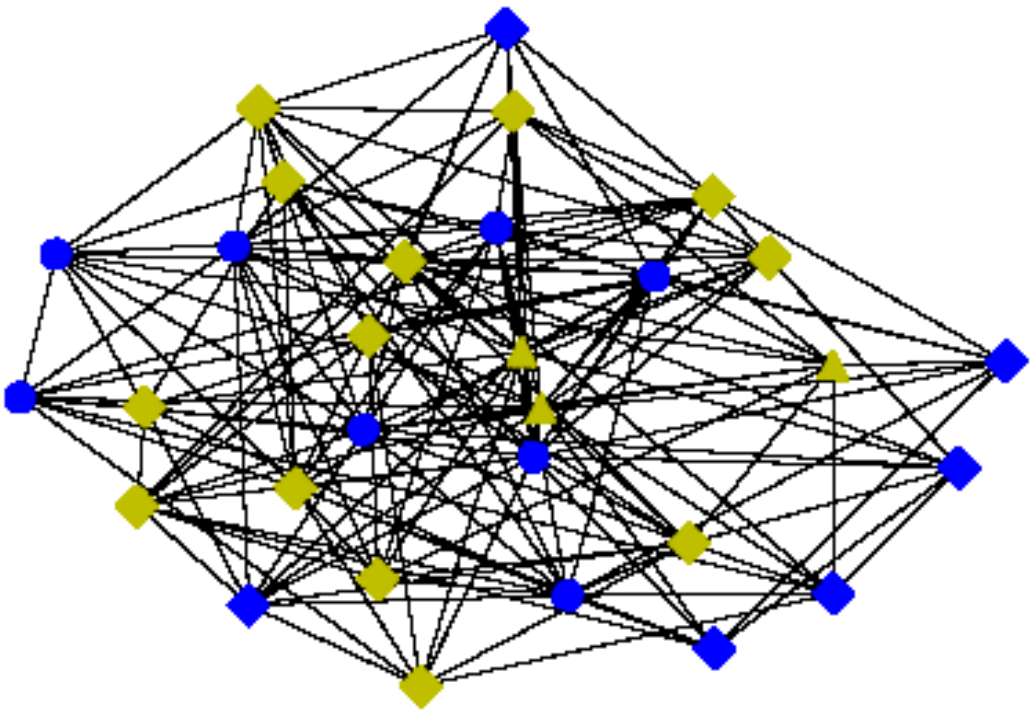
- The number of nodes: 30;
- Type of the network: random connected graph;
- Distribution of initial propensities (attitudes to vaccination): negative – 8, positive – 3, neutral – 19;
- Initially: going to vaccinate – 15, not going to vaccinate – 15;
- Process convergence: formally – 9 iterations, informally – 2 iterations;
- Finally: decided to get vaccination – 16, decided not to get vaccination – 14.

Example 3



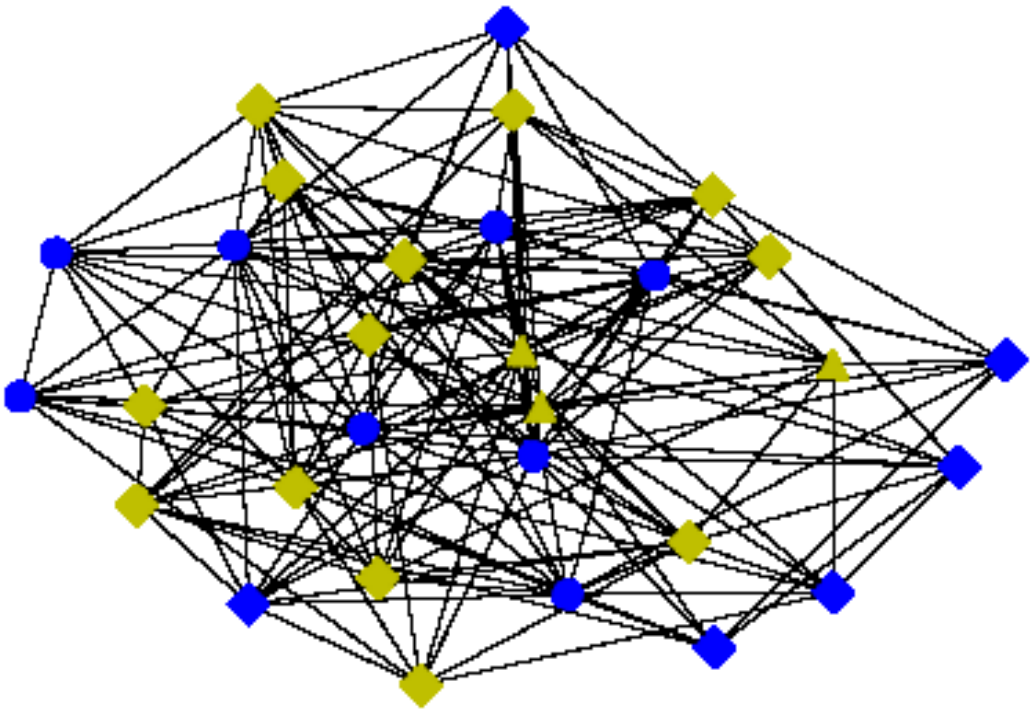
Example 3: Initial state of population, before opinion dynamics)

Example 3



Example 3: Population after the first iteration

Example 3



Example 3: The result opinion dynamics: final state of population after the second iteration

Example 3: Conclusions

- The case of negative dynamics: the number of those who are going to vaccinate increases but not significantly (only one added);
- Possible reasons:
  - agents with different predispositions are highly mixed in the network;
  - agents with a negative attitude have a large number of connections;
- Final result: there is no effect from opinion dynamics.

Conclusions

The opinion dynamics in the network can be represented by various scenarios (from highly negative to highly positive) depending on:

- type of the network;
- the number of connections of the agents with different attitudes to vaccination;
- locations of agents with different attitudes (how mixed they are);
- ratio of the number of agents with different decisions before the start of the opinions exchange;
- what is the propensity to vaccination of agents who are the first disseminators of opinion in the network.

Epidemic Process

Initial Assumptions

It is assumed that

- the opinion dynamics in the population ends before the start of the epidemic rise;
- to simulate a population, it is logical to consider the union of modeled teams into one set:
  - open space offices
  - departments of a large organization
  - classes at school
  - groups in the kindergarten
  - etc..

  let H be the cardinality of this union;
- in real life this union can consist of subpopulations represented by the networks of various configurations;
- we assume that the season epidemic rise can be described by a SIR-like model [Kermack-McKendrick model,1927].

Notations

- H is the total number of agents in the population;
- P is the number of those who did not receive immune protection among the total number of vaccinated;
- P^- is the number of those who did not receive immune protection among the total number of unvaccinated;
- I is the number of infected;
- R is the number of immunized.

P, P^-, I, R are the dynamic functions.

Problem Formulation

The epidemic process can be described by a system of differential equations:

$$\begin{cases} \dot{P} = -a\,P\,I \\ \dot{P^-} = -a^-\,P^-\,I \\ \dot{I} = a\,P\,I + a^-\,P^-\,I - \beta I \\ \dot{R} = \beta I \end{cases} \tag{1}$$

where a, a^- and β are the parameters of the model.

Parameters of the Model

- β is recovery rate:

$$\beta = \frac{1}{T_b},$$

  where T_b characteristic duration of illness ($T_b = 15$ days);
- T is the duration of the seasonal rise ($T = 90$ days);
- a and a^- are found in accordance with real data on vaccination in Russia [Erofeeva M. et al., 2021].

Initial Conditions

- the number of vaccinated V and the number of unvaccinated V^- are defined as the results of opinion dynamics:
  - $P(0) = 0.2\,V$;
  - $P^-(0) = 0.8\,V^-$;
  - 0.2 and 0.8 are 20% and 80% correspondingly (in accordance with the Pareto principle);
- $R(0) = H - P(0) - P^-(0) - I(0)$, where $I(0) = 1$;
- Epidemic start conditions:

$$a\,P(0)\,I(0) + a^-\,P^-(0)\,I(0) - \beta\,I(0) > 0.$$

Problem Formulation

Along with the solution of the system (1) we will search the values of the number L of recovered patients among the vaccinated:

$$L = \int_0^\tau a\, P\, I\, dt, \tag{2}$$

and the number L^- of recovered patients among those unvaccinated:

$$L^- = \int_0^\tau a^-\, P^-\, I\, dt, \tag{3}$$

where τ is length of intervals by months; can take values $\{30, 60, 90\}$.

Numerical Simulations

Example 1

Parameters of the epidemic model:

- $H = 180;$
- $\beta = 0.067$
- $a = 0.001$
- $a^{-} = 0.003$

Example 1

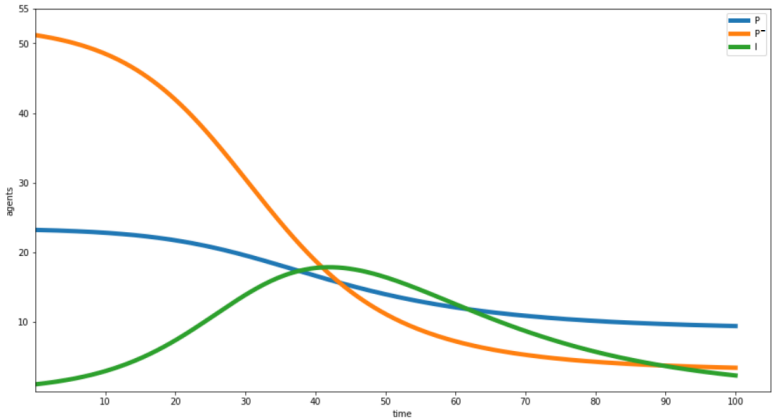


Figure: Example 1. Epidemic process with initial distribution of opinions

- $V = 116$, $V^- = 64$;
- $P(0) = 23.2$, $P^-(0) = 51.2$;
- $L = 13.54$, $L^- = 47.505$, $I_{\max}(42) = 17.83$.

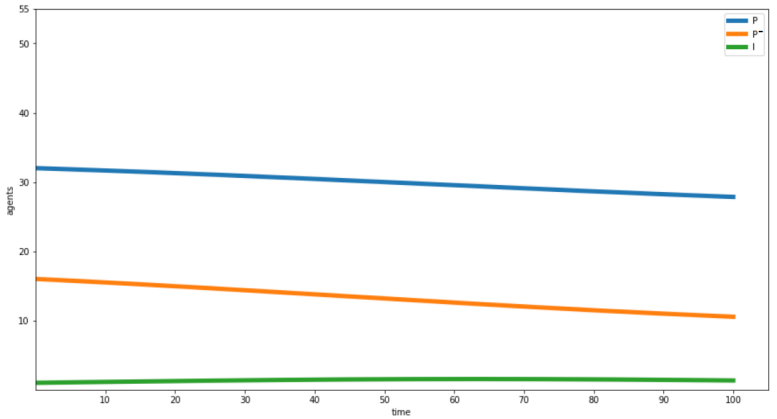


Figure: Example 1. Epidemic process after opinion dynamics

- $V = 160$, $V^- = 20$;
- $P(0) = 32$, $P^-(0) = 16$;
- $L = 3.77$, $L^- = 5.012$, $I_{\max}(62.8) = 1.54$.

Example 1: Results

- after the dynamics of opinions, the initial number of those going to be vaccinated increased from 116 to 160;
- the number of susceptible among the vaccinated has decreased;
- the maximum number of cases decreases 11 times.

Example 2

Parameters of the epidemic model:

- $H = 180;$
- $\beta = 0.067$
- $a = 0.001$
- $a^{-} = 0.003$

Example 2

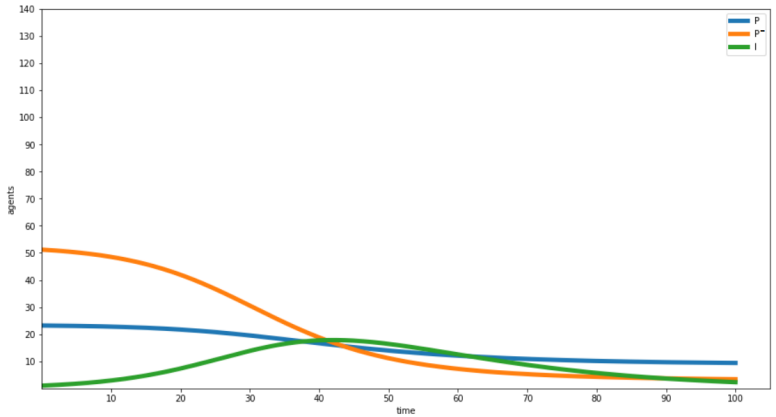


Figure: Example 2. Epidemic process with initial distribution of opinions

- $V = 116$, $V^- = 64$;
- $P(0) = 23.2$, $P^-(0) = 51.2$;
- $L = 13.54$, $L^- = 47.51$, $I_{\max}(42) = 17.83$.

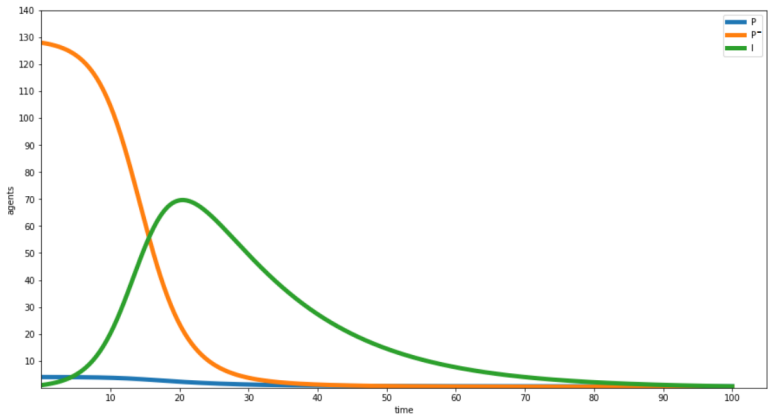


Figure: Example 2. Epidemic process after opinion dynamics

- $V = 20$, $V^- = 160$;
- $P(0) = 4$, $P^-(0) = 128$;
- $L = 3.44$, $L^- = 127.64$, $I_{\max}(20.4) = 69.64$.

Example 2: Results

- there is a negative dynamics of opinions; most are not going to get vaccinated;
- there is a rapid rise in the number of infected, on the 20th day a maximum is reached; all P and P^- will get sick;
- without opinion dynamics there is an increase in the number of infected by 42 days, and the maximum will be no more than 18 people per a day.

Example 3

Parameters of the epidemic model:

- $H = 240;$
- $\beta = 0.067$
- $a = 0.01$
- $a^{-} = 0.001$

Example 3

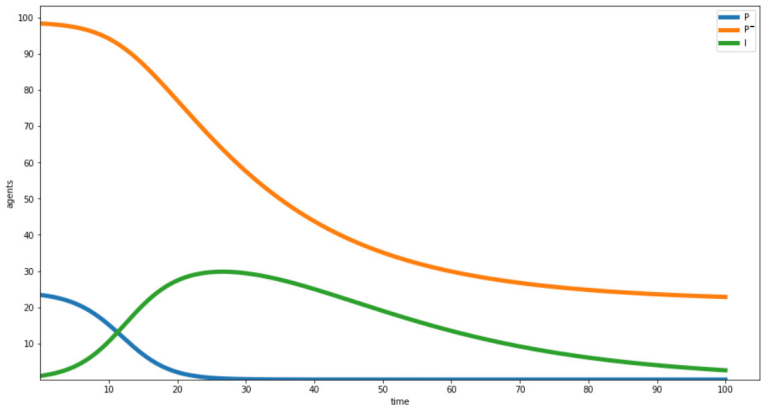


Figure: Example 3. Epidemic process with initial distribution of opinions

- $V = 117$, $V^- = 123$;
- $P(0) = 23.4$, $P^-(0) = 98.4$;
- $L = 23.4$, $L^- = 74.82$, $I_{\max}(26.6) = 29.81$.

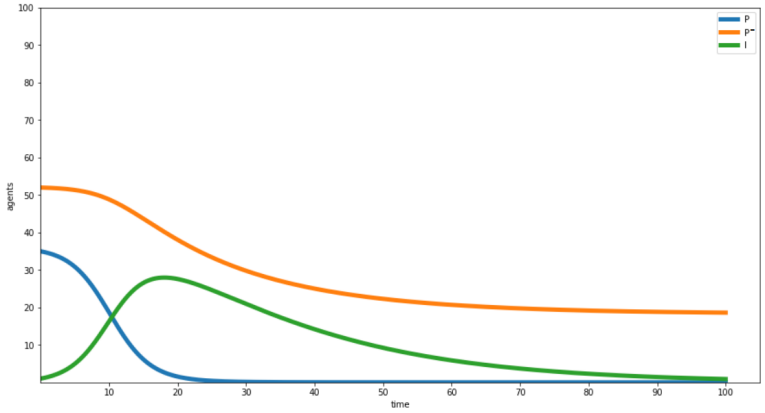


Figure: Example 3. Epidemic process after opinion dynamics

- $V = 175$, $V^- = 65$;
- $P(0) = 35$, $P^-(0) = 52$;
- $L = 34.99$, $L^- = 33.18$, $I_{\max}(18) = 27.97$.

Example 3: Results

- after the opinions dynamics, the number of those who are going to vaccinate increased;
- at the same time, the number of unvaccinated people who recovered from the disease decreased by almost half, but the maximum number of infected people is approximately the same, while $t_{\max}$ shifts to the left;
- most likely this is due to the fact that the parameter $a > a^{-}$ (that is, the rate of disease among vaccinated people is higher).

Conclusions and Prospects

Conclusions

- The dynamics of opinions about vaccination can have both positive and negative effects on the subsequent course of the epidemic in the population.
- The choice of competent ways to manage public opinion (vaccination promotion, availability of information about existing vaccines, etc.) can positively influence on the course of epidemics, increasing the duration of the epidemic reaching its maximum level and reducing the maximum number of cases.
- Such actions have both a humanistic and economic effect: the burden on the healthcare system, the economic burden on enterprises and the state as a whole are reduced.

Prospects

- It is planned to pay more attention to the study of negative scenarios of the dynamics of opinions.
- The model can be improved by including the death process into consideration.
- It is planned to include more detailed statistical data in the process of estimating model parameters.

References:

- Antonova N., Yeritsyan K. *The systematic review of empirical research of factors of refusal from vaccination* // Gigiena i Sanitaria (Hygiene and Sanitation, Russian journal) 2018; 97(7): 664-670. (In Russian)
- Briko N., Mindlina A. et al. *ASSESSMENT OF ATTITUDES TOWARDS IMMUNIZATION IN DIFFERENT GROUPS OF POPULATION OF THE RUSSIAN FEDERATION* // Zh Mikrobiol Epidemiol Immunobiol. Mar (2): 98-103 2017.
- Briko N., Feldblyum I. *The Modern Concept of Development of Vaccine Prevention in Russia* // Epidemiology and Vaccinal Prevention. 18 (5): 4–13. 2019. (In Russian)
- De Groot M.H. Reaching a Consensus // Journal of the American Statistical Association, 1974, vol. 69, No. 345, pp. 118 - 121.

References:

- Gao S., Teng Z., Nieto J., Torres A. *Analysis of an SIR epidemic model with pulse vaccination and distributed time delay* // Journal of Biomedicine & Biotechnology. 2007
- Gubanov D., Novikov D., Chkhartishvili A. Social Networks: Models of Informational Influence, Control and Confrontation. Moscow: Fizmatlit, 2010. (in Russian).
- Gubar E., Kumacheva S., Zhitkova E., Tomilina G. *Modeling of the Impact of Information on Tax Audits on the Risk Statuses and Evasions of Individuals* // Vestnik SPbGU, series 10, 2019, vol.15, pp.245–258.
- Erofeeva M., Stukova M., Shakhlanskaya E., et al. *Evaluation of the preventive effect of influenza vaccines during the epidemic season 2019-2020 in St. Petersburg* // Epidemiology and Vaccinal Prevention. 20 (5): 52–60. 2021 (In Russian)

References:

- Kermack, W.O., McKendrick, A.G. *Contributions to the mathematical theory of epidemics—III. Further studies of the problem of endemicity* // Bltn Mathcal Biology 53, 89–118. 1991.
- Kolesin I., Gubar E., Zhitkova E. *management strategies in medical and social systems* // SPbSU. St.Petersburg. 2014 (in Russian)
- Matz A. *The Modern Origins of Anti-Vaccination Insinuations and Ideology* // Epidemiology and Vaccinal Prevention, № 3 (70). 2013 (in Russian)
- Mazalov V.V., Dorofeeva Y.A., Parilina E.M. Opinion control in a team with complete and incomplete communication // Contributions to Game Theory and Management, 2020. Pp. 324-334.
- Nekovee A., Moreno, Y., Bianconi G. and M. Marsili. *Theory of rumor spreading in complex social networks* // Physica A 374, 2007. pp. 457–470.

References:

- Niazashvili, A. *Individual differences in risk propensity in different social situations of personal development*. Moscow University for the Humanities, Moscow (2007)
- Sandmann F.G. , van Leeuwen E., Bernard-Stoecklin S. et al. *Health and economic impact of seasonal influenza mass vaccination strategies in European settings: A mathematical modelling and cost-effectiveness analysis* // Vaccine 40 (2022) 1306–1315. Elsevier Ltd. 2022
- Saperkin N., Kukunova V. *Vaccination issues and Internet space* // MEDICAL ALMANAH. No. 2, May (26). 2013 (in Russian)
- Wolff G. G. *Influenza vaccination and respiratory virus interference among Department of Defense personnel during the 2017–2018 influenza season* // Vaccine 38 (2020) 350–354. Elsevier Ltd. 2019
- The web-site of the World Health Organization. *https://www.who.int/*.
- The web-site of the Russian Federation State Statistics Service. *http://www.gks.ru/*.

Thank You for Your Attention!