An Agent-Based Model of Infectious Diseases Taking into Account the Role of Immune Cells and Antibodies.

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Abstract An agent-based infection model that takes into account the role of immune cells and antibodies has been constructed, and the effect of various factors on the spread and convergence of infection are analyzed. As a result, it was found that the calculated behavior of the numbers of newly infected, newly recovered, and the infected was qualitatively consistent with the actual phenomenon. It was found that an essential factor for the spread of infection is the number of infected persons with whom a healthy person encounters, while the existence of antibodies is not essential for the fundamental behavior of the spread and converge of infection. Based on these results, the fundamental mechanism for the spread of infection is that the probability of a healthy person encountering an infected person increases progressively, and the primary mechanism for convergence of the infection spread is that the above probability decreases progressively as the number of recovered people increases. It is considered that in order to control the spread of infection while minimizing economic deterioration, it is essential to identify infected persons, regulate their behavior, and minimize the probability for healthy persons encounter infected persons.

Keywords: agent-based model, infectious disease, coronavirus, immune cells, antibodies, pandemic, infection, recovery

1. Introduction

Since the first discovery of the Corona Virus in December 2019 in China, the coronavirus has spread over the world, with the number of infected being still increasing globally. On the other hand, in some countries, including Japan, the infected number has reached a low level as of July 10, 2020 [1], thanks to the regulation of the social movement. A new action of easing such control of social activity is now starting globally to recover the economy while worrying about the emergence of the second stage of pandemic. Under these circumstances, people in the world are going for a new style of life with coronaviruses such as wearing masks and self-regulating social distancing.

Forecasting the emergence of a pandemic has been a significant social issue since many years before, much before the current social needs to seek out a new style of life with coronaviruses. As a result, many mathematical models have been proposed and well known in the literature [1-6].

These mathematical models are classified into deterministic and probabilistic ones. However, they are mostly the system-dynamics type consisting of a set of equations to be solved simultaneously. Each equation describes the time-dependent relationship between the variables that are infection-state-related population, such as the susceptible, the infected, and the recovered. However, these equation-based models have a fatal flaw in that they cannot describe the complex interaction among heterogeneous agents that is the essential cause of the propagation of infectious diseases. Besides, such models do not provide knowledge on the influential factors for the recovery because they do not describe the recovery process after infection.

An agent-based model (ABM) is a modeling method suitable for describing the heterogeneity of the behaviors of agents[7-8]. In ABM, we construct an artificial society on a computer and reproduce various social phenomena from the bottom-up caused by the agents' behavior and interactions. Thus, ABM is an effective way to understand the mechanism and solve economic and social problems [8-11]. ABM has various advantageous features, such as its being able to deal with heterogeneity and discrete phenomenon [7]; among them, the essential element is that it is a bottom-up modeling method.

Since social phenomena emerge as a result of the actions of humans and the interactions among them, we can construct an artificial society using ABM that behaves under the same principle as that of real society. Note that the model can work in this way only when the model is 100% bottom-up type, and its system structure is the same as that of the actual one, the factors of which are indispensable to reproduce the phenomenon under concern [9-11].

ABM has also been applied to the disease problem, as reported in the literature [12-15]. However, most of them are not 100% bottom-up type in that they assume the relationship of aggregate variables such as the distribution of aggregate variables. In the case of the ABM of 100% bottom-up type, the recovering process after the infection is not modeled as 100% bottom-up type in that the infected are assumed to become immune at a certain period after infection [12]. Thus, although the ABM model of this type mimics the spatial interaction among agents that causes infection very carefully, it cannot reproduce the specific behaviors of the increase and decrease of the newly infected, the newly recovered, and the infected without using macroscopic assumptions. Moreover, it cannot reproduce the emergence of the second stage of pandemic after easing the regulation of social movement.

On the other hand, as to the function of innate immune cells and antibodies, it is well known [16] that innate immune cells first attack the virus after infection. After a certain period, antibodies emerge and begin to fight against the virus. According to the statistical data, the death rate due to coronavirus is very low. The number of recovered with antibodies is also small, i.e., the majority of the recovered showed a weak antibody response [18], the feature of which cannot be explained by conventional models. Statistical data of the pandemic also shows that the number of infected, the number of newly infected, and that of newly recovered shows its maximum in different timing.

However, the ABM models so far reported do not consider the epidemic process after infection, thus cannot reproduce the epidemic features mentioned-above during the process of infection and recovery.

This paper developed an agent-based model that takes into account the role of immune cells and antibodies, compared the calculated results with statistical data in the real world, and discusses the mechanism of the pandemic as well as the condition for balancing the control of infection and the promotion of economy.

2. The model

2.1 Outline of the model

This model features that it takes into account the role of immune cells and antibodies, as well as the number of viruses. On the other hand, the process of the interaction among agents is simplified, assuming random movement of agents in the two-dimensional space.

Human-agent is an only object in the model that moves randomly in the two-dimensional space of 1000×1000 every period. The number of human-agent is assumed to be 2000, the initial position in the 2-dimensional space is assigned randomly for each agent. The distance of the movement is assigned every period by a uniform random number between 0 and a predetermined maximum traveling distance. The direction is also assigned every period by a uniform random number between 0 and 360° . One of the individual objects is initially infected, having many viruses, the number of which is an attribute variable. The infected human object is assumed to release a part of the viruses every period in the form of a cough or other means; thus, an agent who meets the infected receives a part of the released viruses at a predetermined virus-absorbing rate, becoming the newly infected. A decrease in the absorbing rate corresponds to wearing masks or other means in the real world. An agent is assumed to meet with another agent when they locate within a distance of 5. If an agent is infected, immune cells attack the viruses every period, discharging a part of the viruses out of the body. The resultant viruses are assumed to multiply by itself at a predetermined increasing rate. After a predetermined period, if the number of viruses is larger than the predetermined minimum number, antibodies are assumed to emerge that attack the viruses with a much larger rate than that of immune cells. When the amount of the viruses is smaller than the critical lower limit at a certain period, the number of viruses is assumed to be zero, with the agent state being changed from the infected to the recovered, thus becoming the newly recovered. The emergence of death is assumed to be negligible because it requires a massive number of population. Therefore, all of the infected agents may be recovered in this model unless the virus-increasing rate is not too large.

The attribute variables of agents and parameter values are presented in Table 1, and characteristic variables calculated in the model are given in Table 2.

The model is programmed by the author using C++ with object-oriented programing. Main classes used in the model is presented in Table 3.

Table 1 Attribute variables of agents and parameter values

Variables	Initial value or definition
Number of agents	2000
Area of network system	1000 × 1000
Maximum Distance of agent's move	100
Critical distance for infection	5
Initial number of the infected	1
Number of virses hold by the infected initially	5000 × 100
Virus increasing rate	1.4, 1.6, 1.8, 2.0
Virus excluding rate by immune cells	0.3 ± 0.1 uniform random number
Virus excluding rate by antibodies	0.5 ± 0.1
Limiting number of steps untile antibody generation	7 ± 2
Virus releasing rate	0.1 ± 0.05
Virus absorbing rate	0.1 ± 0.05
Position (x,y) in the 2 dimentional space	defined at every step
Distance of agent's move	[0,maximum distance] uniform random number
Direction of agent's move	[0° ,360] uniform random number
Agent as an object in the neighbour	defined at every step
Number of virses	calculated at every step
Infection-related state variables	calculated at every step

Table 2 Characteristic variables calculated in the model.

Variables related to individual's attribute	**Variables related to the state of the network system**
Number of viruses	Average number of neighbours per capita
Position in the 2 dimentioanal space	Number of the infected(% per capita)
Agents of nearest neighbour(Object)	Number of the newly infected(% per capita)
Number of viruses contaminated by infection	Number of the newly recovered(% per capita)
Infection-related state variables	Accumulated number of the infected(% per capita)
Uninfected, Infected	Accumulated number of the recovered(% per capita)
Infected with antibody	Number of the recovered with antibody(% per capita)
Infected without antibody	Number of the recovered without antibody(% per capita)
Recovered with antibody	Number of the infected with antibody(% capita)
Recovered without antibody	Number of the infected without antibody(% per capita)

Table 3 Main Classes of C++ used in the model

Human	Moves randomly in the 2-dimentional space. Owns the class Germ as an objet
Germ	Has the set of variables and functions, related to the virus, immune cells and antibodies
Network	Manage the positions of humans and their interaction such as infection
HumanAggregator	Create and manage the set of human objects.
Agent	A super class of Human used for polymorphism
AgentAggregator	A super class of HumanAggregator used for polymorphism
SimulatorApp	Manage the progress of the program
SimuolatorConfig	Manages the parameter variables and files

3. Experimental conditions

3.1 Items of analysis at each time step

Number of the infected (% per capita), Number of the newly infected(% per capita),
Number of the newly recovered with or without antibodies(% per capita)
Human object with whom a human object meet in the 2-dimensional space at each time step.
The average number of the infected with whom a human object meet at each time step.

3.2 Experimental conditions.

The influence of the following factors on the above-mentioned variables is analyzed.

- The effect of virus increasing rate
- The effect of maximum traveling distance at each step.
- The effect of virus-absorbing rate such as using a mask
- The effect of the regulation and mitigation of agents move.

4. Calculated results

4.1 Fundamental behavior during the infection and recovery

4.1.1 Effect of virus increasing rate on the numbers of the infected and recovered

This section describes the calculated behavior of the numbers of the infected and recovered in the case without any countermeasure against disease, where the maximum distance of movement, the virus- absorbing rate, and the attacking rates of immune cells and antibodies is each assumed constant.

Fig.1 shows the changes in the number of infected when the virus increasing rate is changed from 1.4 to 2.0. The number of infected is represented in the unit of the percentage of the total population. As shown in Fig. 1, when the virus increasing rate is between 1.4 and 1.8, the number of infected once increases, shows its peak, and then decreases, ending up the pandemic. These are the cases where the virus-increasing rate is not too large compared to the virus-attacking rate of immune cells or antibodies. When the virus-increasing rate is 2.0, which corresponds to the case where the virus-increasing rate is too large, all of the population is finally infected, and the pandemic does not end. On the other hand, when the virus-increasing rate is too low compared to the virus-attacking rate, the scale of infection becomes too small to be called a pandemic. Thus, the cases where the virus-increasing rate is between 1.4 and 1.8

correspond to the cases observed in the real world in the present model, and we can say that the model well reproduces the fundamental behavior of the pandemic process without introducing any macroscopic assumptions.

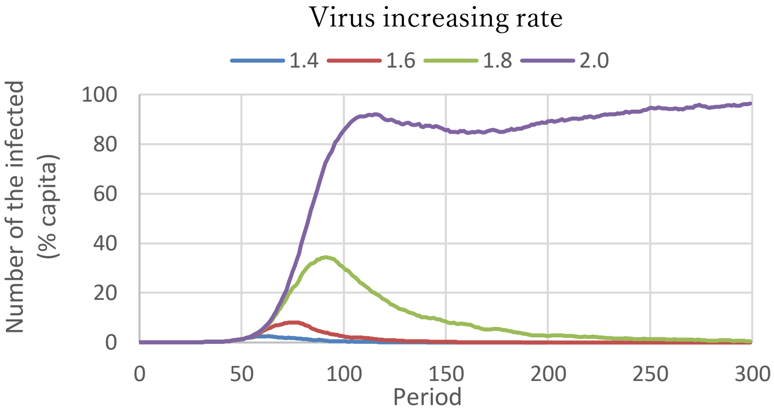

Fig. 1 Effect of the virus-increasing rate on the number of infected.

Let us look through the calculated results of the fundamental behavior of the newly infected and the newly recovered.

As shown in Fig. 2, the number of infected, which is initially one, drastically increases with the period, reaches its maximum, and decreases, the tendency of which is reproduced as a result of the interaction among agents. A similar increase and decrease are reproduced in the number of recovered, as shown in Fig. 3, due to the immune effect of the innate immune cells and antibodies.

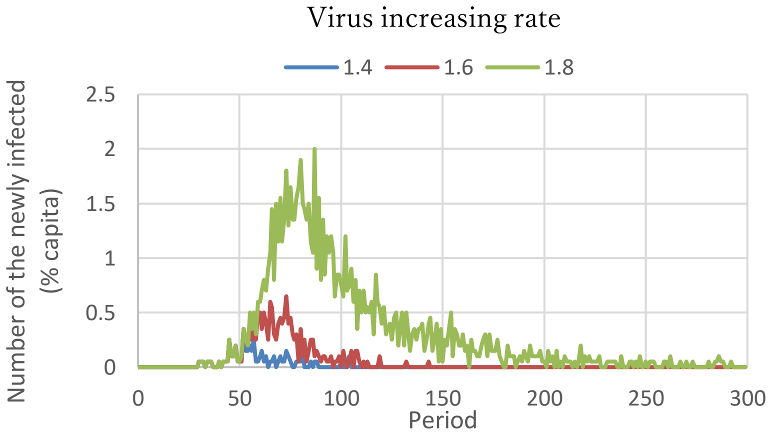

Fig. 2 Effect of virus-increasing rate on the number of newly infected.

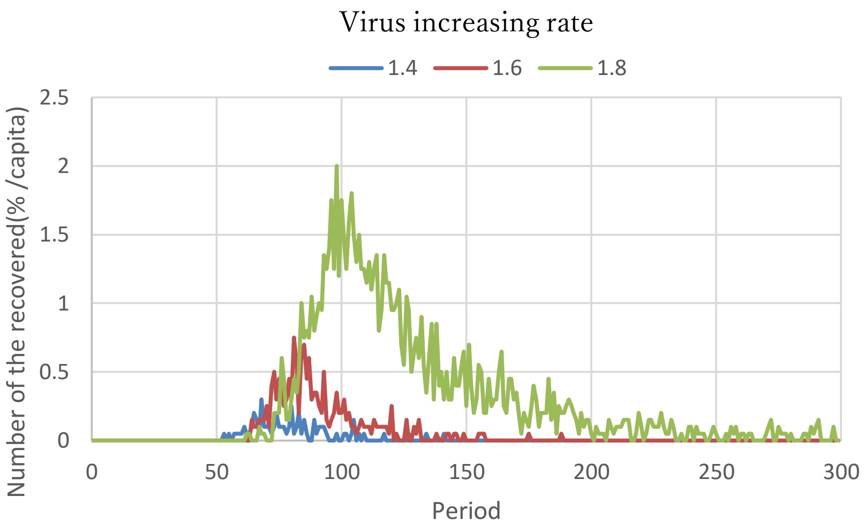

Fig. 3 Effect of virus-increasing rate on the number of newly recovered.

4.1.2 The relationship between newly infected, newly recovered, and the infected.

Fig. 4 shows the numbers of newly infected, newly recovered, and the infected as a function of the period. Note that the number of infected shows its peak at the period between those of the infected and recovered. More precisely speaking, the number of infected becomes maximum at the period where the number of the newly infected equals to that of the newly recovered, as shown in Fig. 5. This fact is obvious from the definition expression of the number of newly infected, as shown in Equation (1). Namely, as the present model neglect the existence of death, the number of the infected in the current term equals that in the previous term when the number of newly infected equals to the number of the recovered, meaning that the number of infected shows it maximum at this period. It is also noticeable that the cumulative number of infected is on the way of increasing at the period where the number of infected becomes maximum, as shown in Fig. 6.

$$N_{infected}{}^{t+1} = N_{infected}{}^{t} + N_{newly\ infected}{}^{t} - N_{newly\ recovered}{}^{t} - N_{newly\ dead}{}^{t} \tag{1}$$

$$where,\ N_{infected} : Number\ of\ \ the\ infected$$

$$N_{newly\ infected} : Number\ of\ \ the\ newly\ infected$$

$$N_{Newly\ dead} : Number\ of\ \ the\ newly\ dead$$

$$t : period$$

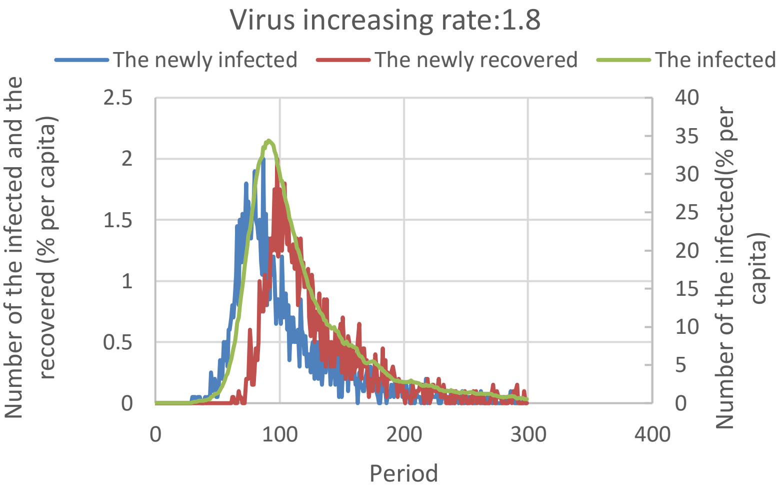

Fig. 4 Change in the number of newly infected, the newly recovered and the infected.

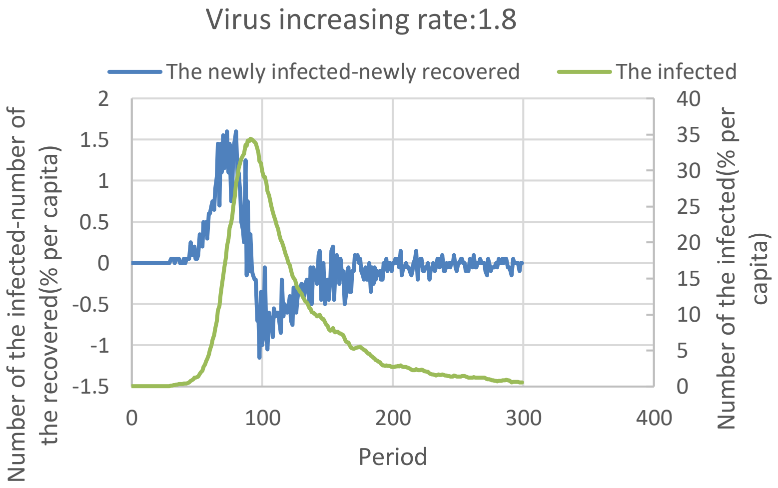

Fig. 5 Change in the number of infected and the difference between the numbers of newly infected and newly recovered.

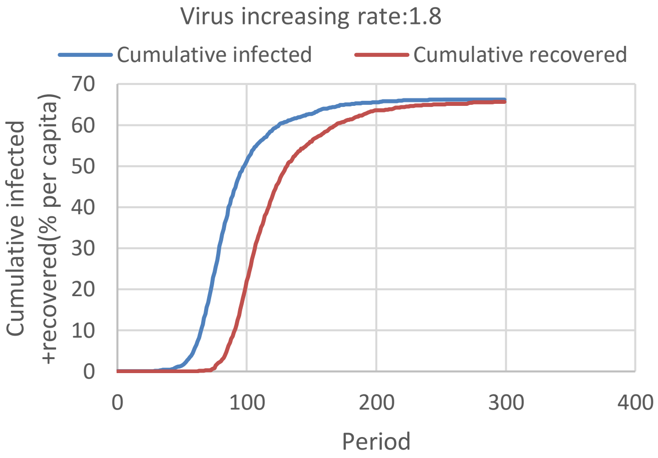

Fig. 6 changes in the cumulative numbers of infected and recovered.

4.1.3 The ratio of the recovered with antibodies to the total number of recovered.

Since the present model neglect the existence of death, all of the infected may finally recover. Whether the infected may recover with antibodies or not depends on the virus-increasing rate. In the case of low virus-increasing rates such as 1.4, 2/3 of the infected recovered without antibodies, as shown in Fig. 7. In the case of the virus-increasing rate being 1.6, 2/3 of the infected recovered with antibodies, as shown in Fig. 8.

This result indicates that whether the people who recovered with antibodies are the majority or not is not the crucial factor for the end of the pandemic.

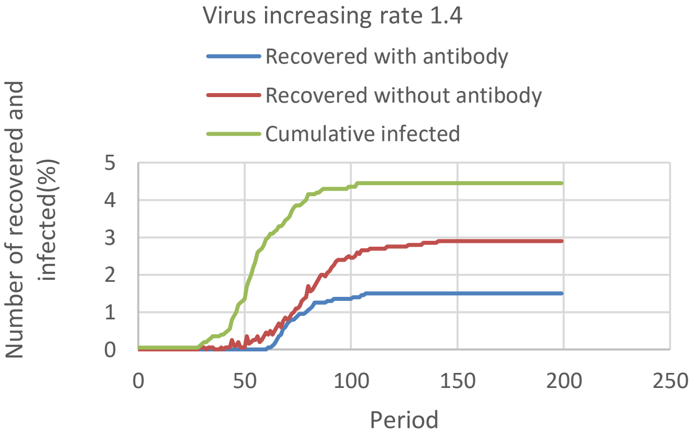

Fig. 7 Changes in the numbers of recovered with and without antibodies and the cumulative number of infected (virus-increasing rate is 1.4).

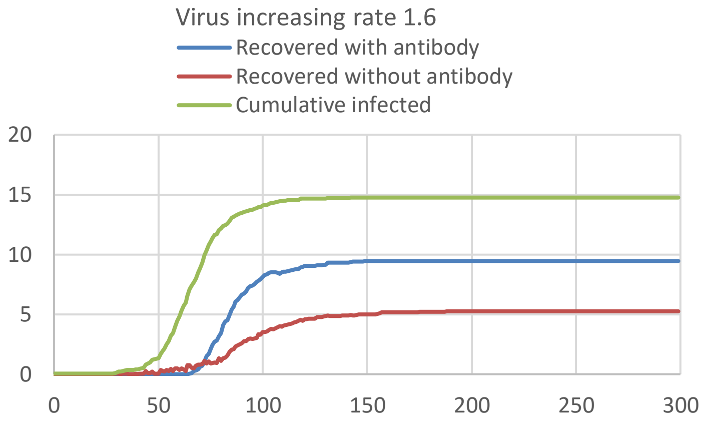

Fig. 8 Changes in the numbers of recovered with and without antibodies and the cumulative number of infected (virus-increasing rate is 1.6).

4.1.4 Effect of the virus-increasing rate on the number of infected neighbors

In the present model, the objective agent who exists within the range of 5 is called a neighbor. The neighbor who is infected is called an infected neighbor.

Fig. 9 and Fig. 10 represent the effect of the virus-increasing rate on the average number of infected neighbors and the ratio of the infected among all neighbors. Both factors show quite a similar behavior as those of the newly infected, newly recovered, and infected, as shown in Fig. 9 and Fig. 10.

When looking at the correlation between these factors, the number of infected increases with the number of infected neighbors, as shown in inf Fig. 11. The source of scattering in Fig. 11 is considered as the scattering of the number of viruses at the time of infection.

From this, we can understand that the leading cause of the spread of infection is that a healthy person encounters the infected person, the repetition of which increases the probability of the healthy person to meet with the infected, causing a progressive increase in the number of infected.

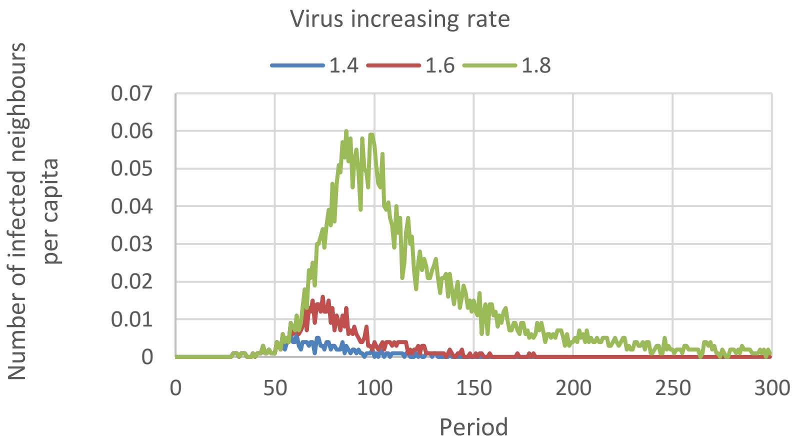

Fig. 9 Effect of virus-increasing rate on the average number of infected neighbors.

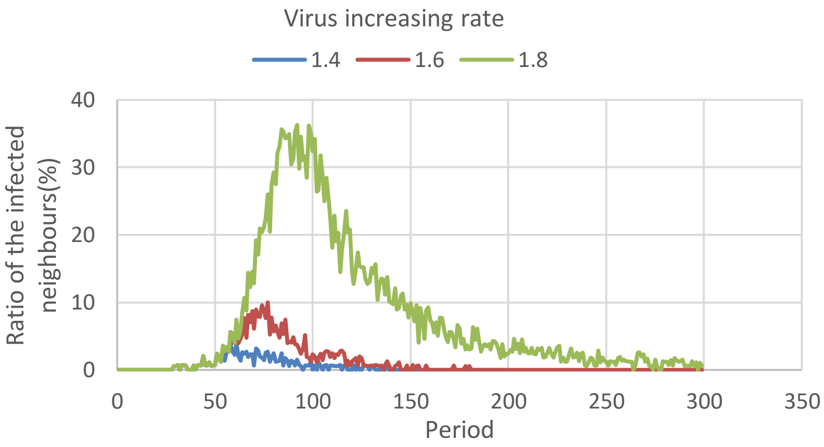

Fig. 10 Effect of virus-increasing rate on the ratio of the infected neighbors to the total number of neighbors.

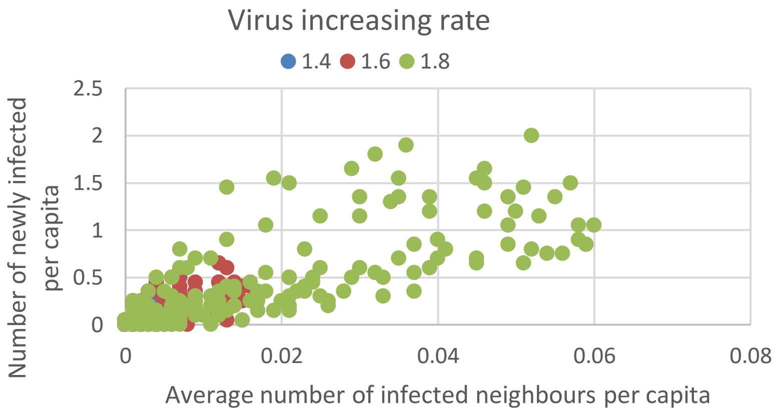

Fig. 11 relationship between the number of newly infected and the average number of infected neighbors.

4.1.4 Effect of maximum traveling distance on the number of infected

Since the present model assumes the movement concerning distance and direction as random, the probability of the uninfected to meet with the infected depends on the maximum traveling distance.

The calculated results presented in the previous sections correspond to the cases where the maximum traveling distance is 100. Now, let us look through how the estimated numbers of the infected, etc. are affected by doubling the maximum traveling distance.

Fig. 12 and Fig. 13 show the effect of the maximum traveling distance on the numbers of infected and newly infected. Note that both factors become much more significant by doubling the maximum traveling distance. The reason for this tendency is that, as shown in Fig. 14, with increasing the maximum traveling distance, the average number of infected neighbors increases, namely the uninfected may meet with the infected more often. Besides, the number of the recovered with antibodies increases with increasing the maximum traveling distance as shown in Fig. 15.

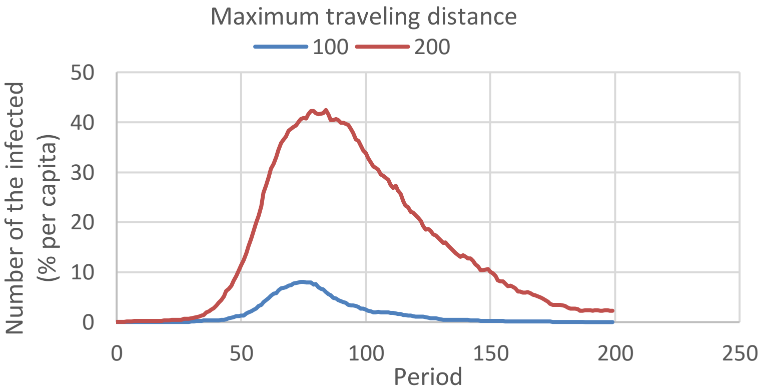

Fig. 12 Effect of the maximum traveling distance on the number of infected (virus-increasing rate :1.6).

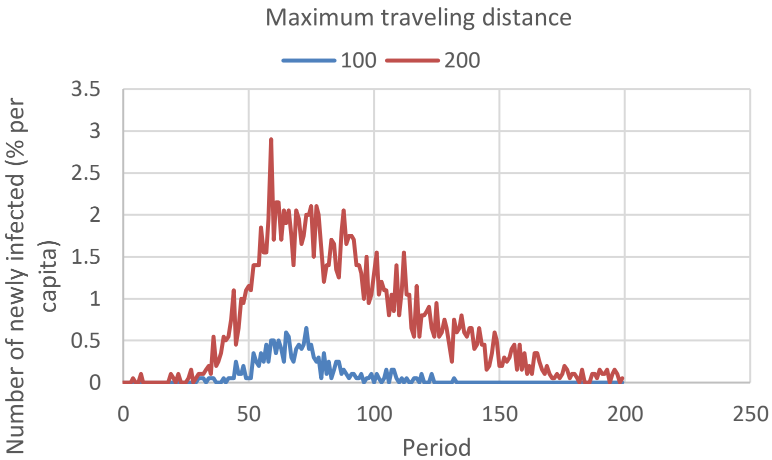

Fig. 13 Effect of the maximum traveling distance on the number of newly infected (virus-increasing rate:1.6)

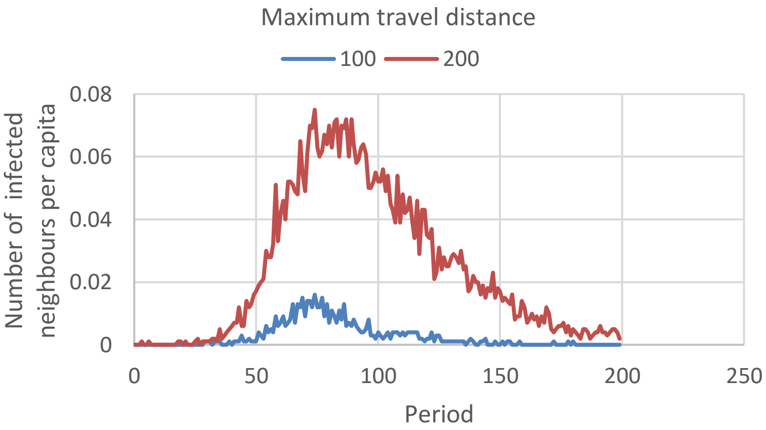

Fig. 14 Effect of the maximum traveling distance on the average number of the infected neighbors.(virus-increasing rate: 1.6)

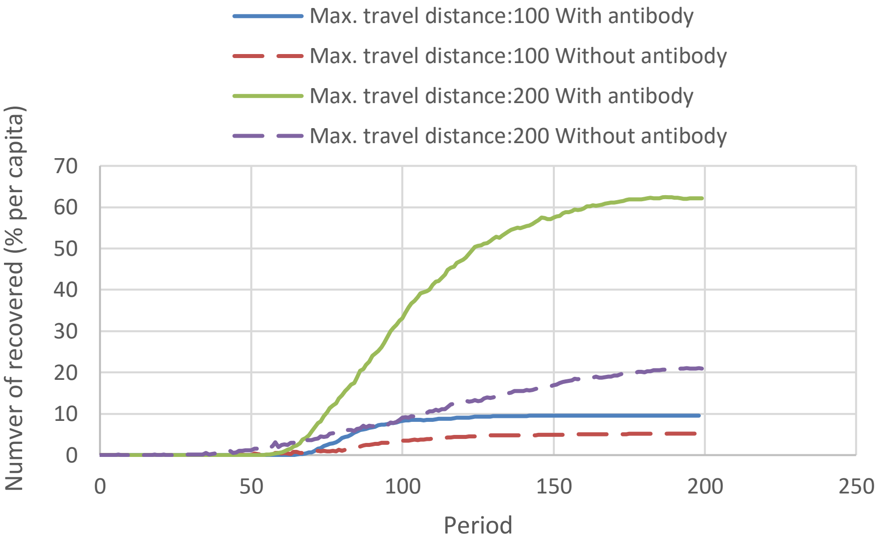

Fig. 15 Effect of maximum traveling distance on the number of the recovered with and without antibodies. (virus-increasing rate: 1.6)

4.1.6 Effect of virus-absorbing rate on the number of infected

As explained in section 2.1, the effect of the virus-absorbing rate corresponds to the effect of wearing masks or other infection prevention measures.

Fig. 16 shows the effect of the virus-absorbing rate on the number of infected, indicating that the number of infected drastically decreases with decreasing the virus-absorbing rate. From this result, wearing masks may be effective for decreasing the number of viruses at the time of infection.

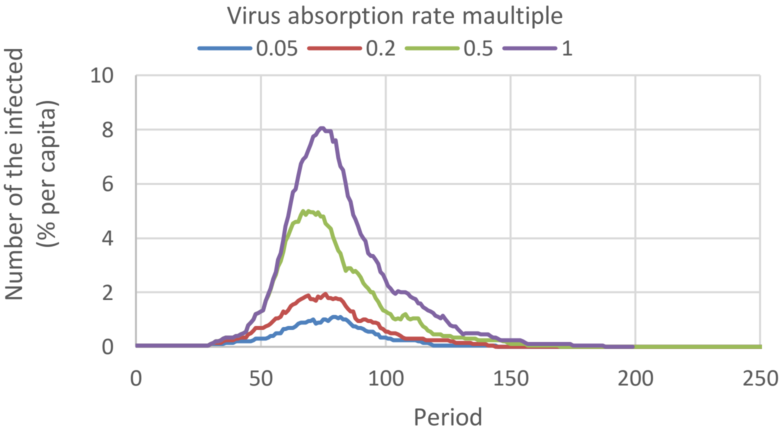

Fig. 16 Effect of the virus-absorbing rate on the number of infected.

4.2 Comparison of the calculated results with the real data.

Fig. 17 shows the changes in the numbers of infected and recovered, and Fig 18 shows the changes in the number of infected in the real data observed in Japan. Note that the peak value of the newly infected emerges around April 15, the peak value of the newly recovered appears around May 10, and the time when both indices are almost the same appears around April 30. Besides, the peak of the number of infected appears around April 30.

Thus, the peak value of newly recovered appears later than the peak value of newly infected, and the period at which the number of infected shows a peak value coincides with the period at which the number of newly infected and the number of newly recovered are almost the same. This tendency coincides with the calculated results shown in Fig. 4 and Fig. 5. Namely, we can conclude that the model well reproduces the fundamental behavior of the number of infected and recovered.

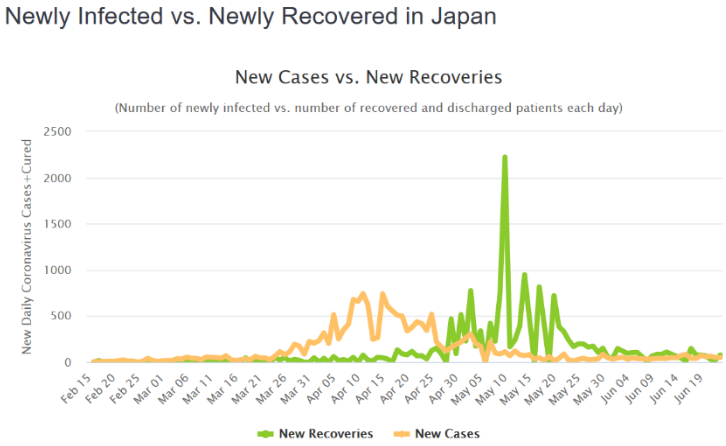

Fig. 17 Changes in the number of infected and recovered in Japan as of June 20,2020.[17)]

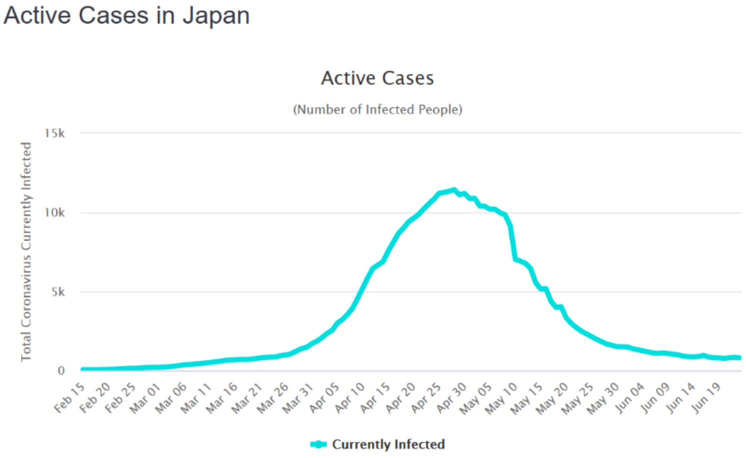

Fig. 18 Change in the number of infected in Japan as of June 20,2020[17].

The change in the accumulated number of infected is shown in Fig. 19. This result indicates that the period at which the number of infected shows its peak value is on the way of increasing accumulated number of infected, which is also coincident with the calculated tendency, given in Fig. 6.

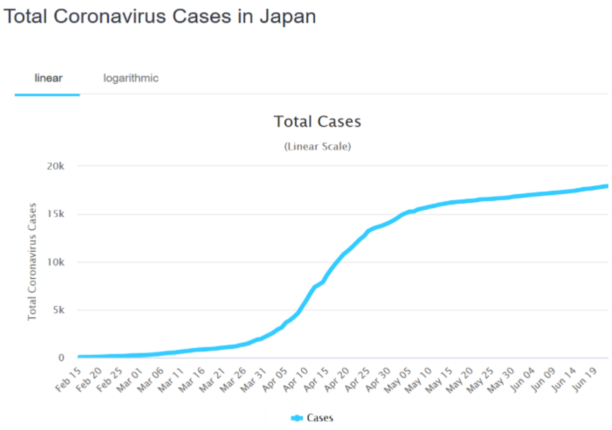

Fig. 19 Change in the accumulated number of the infected in Japan as fo June 20, 2020[17].

4.3 Regulation and mitigation of movement and the effect of virus-absorbing rate

4.3.1 Effect of regulation and mitigation of movement

Fig. 20 shows the changes in the number of infected in the base condition and the experimental conditions. In the experimental conditions, the maximum traveling distance is decreased by 0.2 times or 0.1 times during the period between 50 and 100 and is returned to the original value after a period of 100.

Note that when the maximum traveling distance is decreased by 0.2 times, the peak value of the number of newly infected greatly decreases, while it increases again after the end of the restriction, namely, the second wave of pandemic arises. On the other hand, when the maximum traveling distance is decreased by 0.1 times, namely, when the regulation is applied thoroughly, the emergence of the second wave of the pandemic is not remarkable.

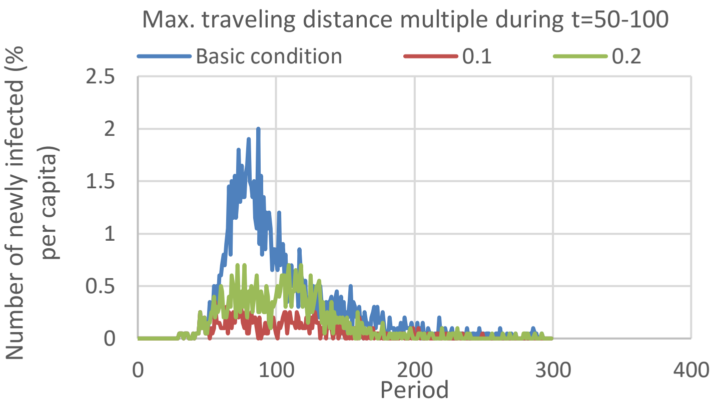

Fig. 20 Effect of temporary regulation of traveling distance and its release on the number of newly infected.

(virus-increasing rate: 1.8)

Similar behavior is observed in the case of the average number of infected neighbors and the number of infected, as shown in Fig. 21, and Fig. 22. Namely, the emergence of the second wave of the pandemic is remarkable in the case of loose regulation and is not impressive in the case of strict control. The reason for this is that the number of infected just before releasing the regulation is small, and therefore, the probability of meeting with the infected becomes low in the case of strict regulation.

The number of recovered with antibodies is smaller in the case of strict regulation, as shown in Fig. 23, indicating that the increase in the number of recovered with antibodies is not the influential factor for preventing the emergence of the second wave of the pandemic.

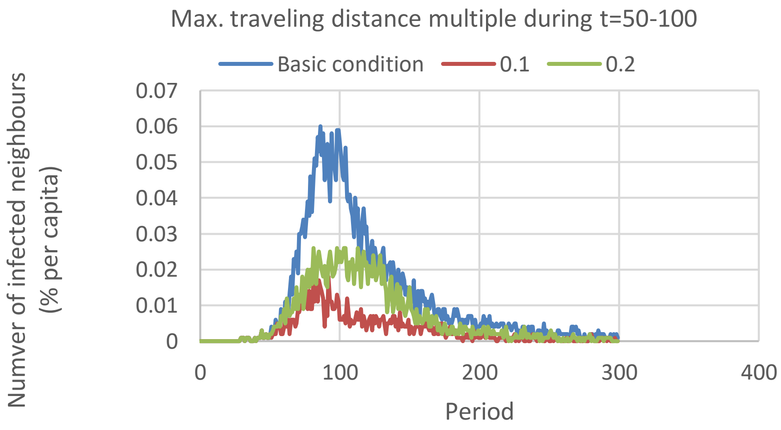

Fig. 21 Effect of temporary regulation of traveling distance and its release on the number of infected neighbors. (virus-increasing rate: 1.8)

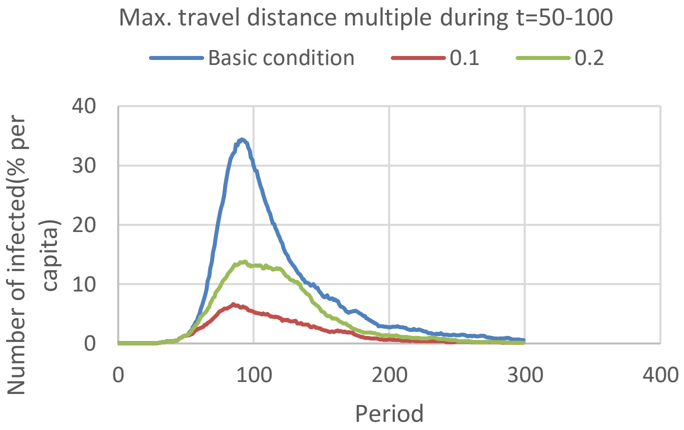

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Fig. 22 Effect of temporary regulation of traveling distance and its release on the number of infected. (virus-increasing rate: 1.8)

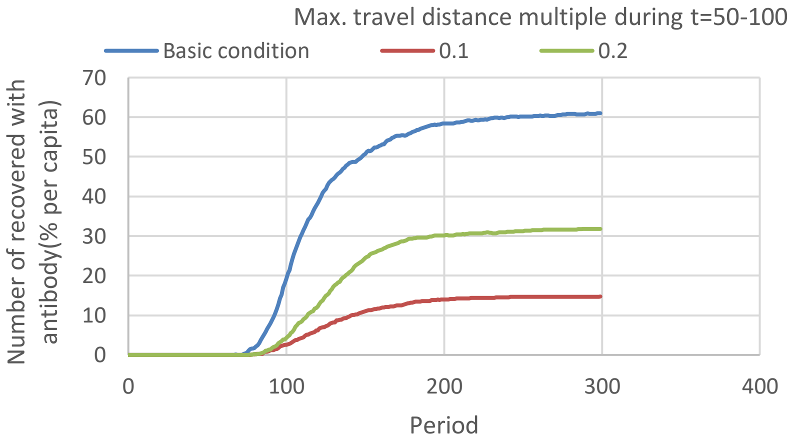

Fig. 23 Effect of temporary regulation of traveling distance and its release on the number of recovered with antibodies. (virus-increasing rate: 1.8)

4.3.2 Effect of the virus-absorbing rate on the infection behavior during the regulation and mitigation of movement

This section describes the effect of the absorbing rate on infection behavior during the regulation and mitigation of movement. Fig. 24 shows the number of newly infected for different patterns of decreasing the virus-absorbing rate. Here, the maximum traveling distance is decreased by 0.2 times only during the periods of 50 and 100. The periods are divided into three sections, i.e., less than 50, between 50 and 100, and after 100. The virus-absorbing rate is changed for each section, and the notation 1-1-1,1-0.2-1,1-0.2-0.2 in Fig. 24 represents the set of multiples for each section, respectively. For example, the notation 1-0.2-0.2 represents a pattern of changing the virus-absorbing rate, where it is decreased by 0.2 times in segments two and three.

As shown in Fig. 24, the second wave of pandemic arises, after the period of 100 where regulation is released, in the case of the pattern 1-1-1. In the case of the pattern 1-0.2-1, the emergence of the second wave of the pandemic is not remarkable, but the number of newly infected slightly increases after a period of 100. On the contrary, in the case of the pattern 1-0.2-0.2, the second wave of a pandemic does not arise, indicating that strict prevention measure against infection is quite effective for preventing the emergence of the second wave of the pandemic.

This tendency is more clearly observed in the number of infected, as shown in Fig. 25.

A similar tendency is also seen in the average number of infected neighbors, as shown in Fig. 26. This result indicates that the reason for the effect of the virus-absorbing rate on the number of newly infected is that the decrease in the virus-absorbing rate results in an increase in the number of newly recovered, thus decreasing the probability of the uninfected to meet with the infected.

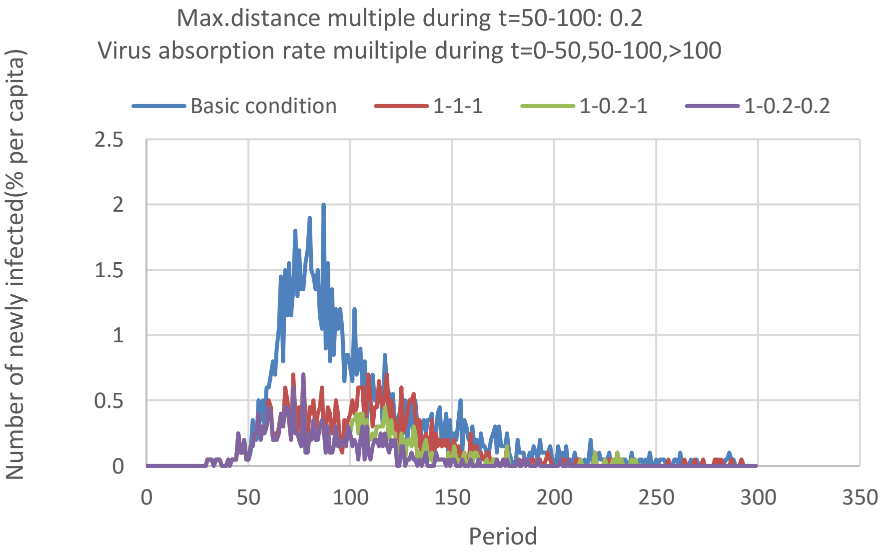

Fig. 24 Effect of the virus-absorbing rate on the number of newly infected when movement regulation is applied.

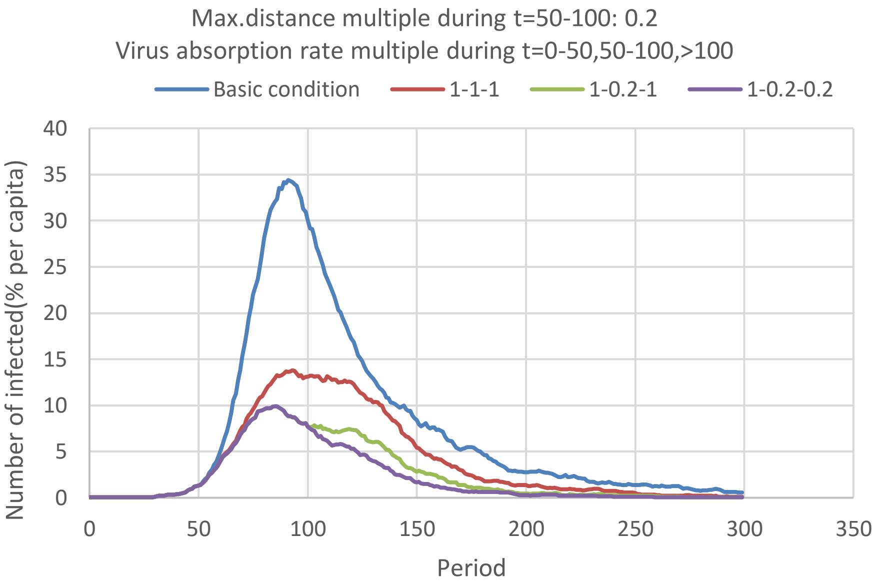

Fig. 25 Effect of the virus-absorbing rate on the number of infected when movement regulation is applied.

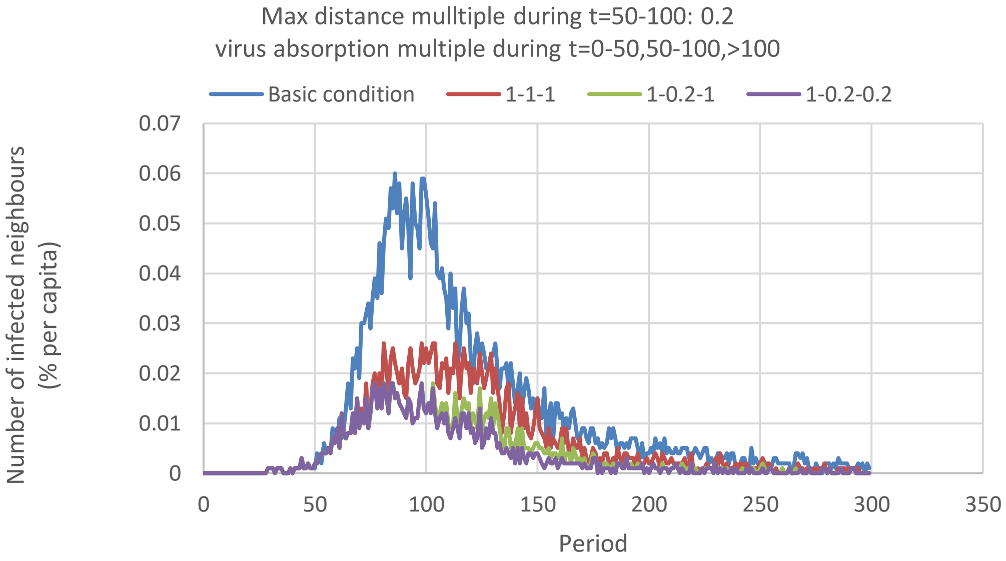

Fig. 26 Effect of the virus-absorbing rate on the average number of infected neighbors when movement regulation is applied.

4.4 Infection behavior when antibodies do not exist

- Fig. 27 shows the behavior of infection and recovery when antibodies do not exist.

It is noticeable that the numbers of newly infected, newly recovered, and the infected shows a similar behavior as given in Fig. 4, which represents the case with antibodies.

- This result indicates that the existence of antibodies is not an essential factor in the mechanism of the fundamental behavior of increasing and decreasing the number of infected, the detail of which will be discussed in the next section.
- However, in the case without antibodies, the virus-increasing rate that is necessary to reproduce the fundamental behavior of infection and recovery significantly decreases compared to the case with antibodies. In the real world, the virus increasing rate might be constant and inherent to the type of virus. When the virus-attack rate is too low compared to the virus-increasing rate, then antibodies that have more strong ability to attack the virus emerge, and most of the infected might recovered by the work of immunity.
    - Therefore, although antibodies are not essential for the fundamental mechanism of infection and recovery, the role of antibodies might be indispensable for the stable end of the pandemic. Here, it is also noted that the ratio of the recovered with antibodies is not necessarily 100 % for the stable end of the pandemic, rather a few percentages of the ratio could be enough, as evidenced in Figs. 7,8, and 15.

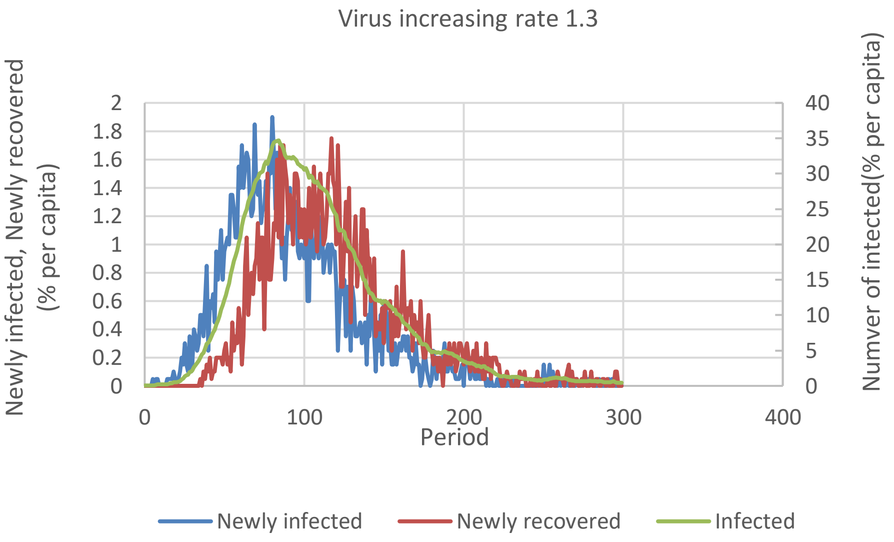

Fig. 27 An example of the calculated behavior of the newly infected, newly recovered, and the infected in the case without antibodies, showing a similar pattern of the start and end of the pandemic in the case with antibodies shown in Fig. 4.

5. Discussion

5.1 The fundamental mechanism of the infection spread and convergence

First, let us assume that we can neglect the existence of death because the ratio of the dead people is far small compared to the infected people. Therefore, the presence of death is not essential for considering the fundamental mechanism of the infection spread and convergence.

Then, essential factors concerning the mechanism are the numbers of newly infected, newly recovered, and infected. These factors are related to each other. Namely, the period at which each essential factor reaches its maximum is in the order of the newly infected, infected, and recovered. Besides, the period at which the number of infected shows its peak is coincident with the period at which the number of newly infected equals to the number of newly recovered. This tendency is consistent in the cases with and without antibodies. Furthermore, there is a positive correlation between the number of newly infected and the average number of infected neighbors at each period.

These facts indicate the fundamental mechanism of the infection and convergence as follows.

Even in the case where the infected person is initially only one, if the infected and uninfected persons move around, they are inevitably meet within a few meters in some time, causing the uninfected to be infected. The route of infection includes splash infection and contact infection. In any case, if the healthy person meets with the infected person in a close area, a part of the viruses disposed of the infected in the form of cough, etc. will be transferred inside the body of the healthy person, causing an infection. Thus, if the number of the infected become double, the probability for the healthy person to meet with the infected becomes double, and the number of the infected increases progressively. On the other hand, during the spread of infection, recovered persons may appear among the early infected people, the number of which increases with the period. The increase in the number of the recovered decreases the probability for the healthy person to meet with the infected, causing the rate of increase in the number of new infections slowed down. At some point, the number of newly infected peaks, and then decreases as the number of recovered person increases.

In short, the fundamental mechanism of infection spread is the progressive increase in the meeting probability of a healthy person with infected people. The mechanism of convergence is that this probability decreases during the infection process due to an increase in the number of recovered people.

Note that the existence of antibodies is not essential for this fundamental mechanism. However, the existence of antibodies may effectively increase the number of recovered, thereby decreasing the probability of a healthy person encountering an infected person. Thus, the presence of antibodies has the function of suppressing the spread of infection and stabilizing the convergence of infection.

5.2 A proposal for the effective strategy for preventing the pandemic while keeping the economy

Restricting the movement of people is one of the effective measures to control the spread of infection. However, movement restrictions cause economic activity to stagnate and worsen the economy. In order to control the spread of infection while minimizing economic deterioration, it is necessary to minimize the probability that healthy people will encounter infected people. Since the number of infected people is generally far smaller than the number of healthy people, it is extremely irrational to limit the behavior to the whole population without distinguishing between the two.

Therefore, the following measures are considered to be effective in achieving both economic deterioration prevention and infection spread control. However, it is assumed here that the vaccine has not yet been developed, which is the current situation.

1) Thorough discrimination between infected and healthy persons

Expanding the number of PCR tests: A system that can perform PCR tests as many times as desired.

2) Social isolation of infected persons

- Socially identify and isolate infected persons, and limit the actions of infected persons only.

  Hospital isolation, hotel isolation, etc.

- Personally recognize that he is an infected person or a healthy person, and if he is infected, refrain from acting.

  Voluntary isolation at home

In addition to the PCR test, self-identification by thermometry is also considered effective for identifying an infected person or a healthy person at the individual level. In other words, recognize your normal heat (generally changes during the day), and if your body temperature is higher than the normal heat in each time zone, refrain from your actions—the same after going out.

3) Thoroughly isolate infected persons and take preventive measures in dense places (such as a night resort).
  ・ Temperature measurement of visitors. Refuse to enter the store if a visitor has a high body temperature because he could be an infected person.
  ・In order to ensure the above, set an upper limit on the number of visitors in the case of a group entry.
  ・Thorough infection prevention measures must be taken inside the store.
  ・Legal penalties will be provided to those managers or firms who do not take these measures.

4) Public grasp of the numbers of newly infected, newly recovered, and the infected and public announcement. These items should be conducted rapidly (on the same day, etc.).

5) Other measures similar to the above.

6. Conclusions

An agent-based infection model that takes into account the immune cells, antibodies, and the number of viruses, has been constructed. Using this model, this paper analyzed the effect of various factors on the spread and convergence of infection as well as comparing the calculated results with the real data, discussed the mechanism of the spread and convergence of the pandemic, and proposed a set of countermeasures against it. As a result, the following facts were revealed.

1) The calculated behaviors of the numbers of newly infected, newly recovered, and the infected were qualitatively consistent with the actual phenomenon.
2) The percentage of antibody holders among the recovered varies from several% to several tens% depending on the calculation conditions. It is found that the spread of infection could be converged even if the proportion of the antibody holders is small.
3) The fundamental mechanism for the spread of infection is that the probability of a healthy person encountering an infected person increases progressively, and the primary mechanism for convergence of the infection spread is that the above probability decreases progressively as the number of recovered people increases.
4) Measures to reduce the virus absorption rate by wearing a mask or face shield etc. are effective in suppressing the spread of infection.
5) Removal of restrictions after behavioral restriction may result in a re-increase in the number of infected persons (second wave) when restrictions are incomplete or depending on the time. In this case, wearing a mask is also effective in preventing the appearance of the second wave.
6) In order to control the spread of infection while minimizing economic deterioration, it is essential to identify infected persons among healthy persons, limit the behavior of infected persons only, and minimize the probability that healthy persons will encounter infected persons.

REFERENCES

1. Bailey, N.T. J. : The Mathematical Theory of Infectious Diseases(Mathematics in Medicine series) Graffin, London (1975).
2. Li, M.Y. : An Introduction to Mathematical Modeling of Infectious Diseases (Mathematics of Planet Earth), Springer (2019)
3. Britton, T. and Ball, F. : Stochastic Epidemic Models with Inference (Lecture Notes in Mathematics), Springer (2019)
4. Marchuk, G.I. : Mathematical Modeling of Immune Response in Infectious Diseases(Mathematics and Its Applications), Kluwer Academic Publishers (2019)
5. Anderson, R.M. and May, R.M. : Infectious Diseases of Humans: Dynamics and Control, Oxford University Press, NewYork (1991).
6. Vynnycky, E. and White, R. : An Introduction to Infectious Disease Modelling, Oxford University Press, New York (2010)

7. Wilensky, U. and Ran, W. : An Introduction to Agent-Based Modeling, The MIT Press, London (2015)
8. Epstein, J.M., Axtell, R. : Growing Artificial Societies,(Social Science from the Bottom Up), MIT Press, London (1996)
9. Ogibayashi, S and Takashima, K : Influence of Inefficiency in Government Expenditure on the Multiplier of Public Investment, Comput Econ (2017) 50:549–577, DOI 10.1007/210614-017-9671-y
10. Ogiayashi, S., Takashima, K. : System Structure of Agent-Based Model Responsible for Reproducing Business Cycles and the Effect of Tax Reduction on GDP," Journal on Policy and Complex Systems, Vol.5, No2, Fall, pp. 37-59 (2019)
11. Ogibayashi, S. and Shinagawa, K. : Model Structure of Agent-Based Artificial System for Reproducing the Emergence of Bullying Phenomenon, Proceedings of the 2018 Conference of the Computational Social Science Society of the Americas, Springer, pp229-250 (2020)
12. Perez, L. and Dragicevic, S. : An agent-based approach for modeling dynamics of contagious disease spread, International Journal of Health Geographics,8,50,(2009) https://doi.org/10.1186/1476-072X-8-50
13. Li, Yan et al. Agent-Based Modeling of Chronic Diseases: A Narrative Reviews and _future Research Directions, PREVENTING CHRONIC DISEASE Public health research, practice, and policy, 13, E69, May (2016)
14. Tuomisto, J.T., et al. : An agent-based epidemic model REINA for COVID-19 to identify destructive policies, April (2020), https://doi.org/10.1101/2020.04.09.20047498
15. Rockett, R.J. et al. : REVEALING COVID-19 TRANSMISSION BY SARS-CoV-2 GENOME SEQUENCING AND AGENT BASED MODELING, APRIL (2020), https://doi.org/10.1101/2020.04.19.048751
16. David Eden,: Beyond the antibodies: How our immune system may protect us against COVID-19 infection, https://abcnews.go.com/Health/antivodies-/story?id=71879020
17. Worldmeter/coronavirus_updates https://www.worldometers.info/coronavirus/country/japan/
18. https://www.dailymail.co.uk/health/article-8363125/Not-recovered-coronavirus-patients-develops-neutralizing-antibodies.html