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Effect of Death on the Spread of COVID-19 Evaluated by a Flexible Compartment Model

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Abstract

Death is the most serious damage. However, from one perspective of the infection process, the deaths of infected individuals refer to the deaths of infectious individuals, that is, the deaths of 'spreaders' who can spread the infection. According to the traditional and conventional epidemiological models, such as the SIRD models, when deaths occur among infected individuals, since the number of spreaders decreases, the total number of infected individuals decreases. On the other hand, deaths of infected individuals decrease the number of recovered individuals in the community, increase the contact rate between infected and susceptible individuals, and could lead to more infected individuals. Which one is correct: "If deaths occur, the total number of infected individuals will decrease," or "If deaths occur, the total number of infected individuals will increase"?

Using a flexible compartment model specific to COVID-19, the change in the number of infected individuals when deaths occur among infected individuals was calculated for the cases with several fatality rates and with several symptomatic rates, and for the case where reinfection occurs.

In the SIRD model, when deaths occurred among infected individuals, since the decrease in the number of spreaders was directly reflected in the calculation and the number of contacts between infected individuals and susceptible individuals decreased, the total number of infected individuals decreased with an increase in fatality rate. In the flexible compartment model, when deaths occurred among infected individuals, the number of recovered individuals and the current population of the community decreased, which increased the contact rate between infected and susceptible individuals and increased also the infection coefficient, thereby the total number of infected individuals increased with an increase in fatality rate. Regarding the cases where reinfection occurred, several epidemics (outbreaks) inevitably occurred, regardless of whether deaths occurred. The duration of infection through all these epidemics became shorter when deaths occurred than when deaths did not occur. However, the final total number of infected individuals in the end became greater when deaths occurred than when no deaths occurred.

Keywords: *Compartment model, contact rate, COVID-19, Death, Effect of death, Fatality rate, Flexible compartment model, Infected, Infection during the latent period, Isolation, Recovered, Reinfection, SIRD model, Susceptible, Symptomatic rate.*

1. Introduction

It goes without saying that death, whether direct (such as from respiratory illnesses) or indirect (such as from worsening underlying medical conditions/pre-existing illnesses), is undoubtedly the most serious damage, meaning the loss of valuable social, economic, and mental resources. However, from the perspective of the infection process, the deaths of infected individuals mean the "deaths of individuals who are infectious", that is, the deaths of "spreaders" who have the potential to spread the infection.

For deaths from COVID-19, traditional and commonly used conventional epidemiological models, extended from the SIR (Susceptible-Infected-Recovered) model, such as the SIRD (Susceptible-Infected-Recovered-Dead (Death)) model, and the SEIRD (Susceptible-Exposed-Infected-Recovered-Dead (Death)) model, include a compartment of "Dead (D)", which specifically represents the number of dead individuals. By using this "Dead (D)" compartment, it is possible to estimate the number of dead individuals [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15]. The "Dead (death)" compartment in these models works mathematically as the "individuals who should be removed due to death" compartment; that is, "death" results in the removal of infected individuals who could spread the virus from the community.

Specifically, the SIRD model is composed of the following differential equations:

1. $dS(t)/dt = -\beta S(t)I(t)/N$ (Susceptible; change)

2. $dI(t)/dt = \beta S(t)I(t)/N - (\gamma + \delta)I(t)$ (Infected; change)

3. $dR(t)/dt = \gamma I(t)$ (Recovered; change)

4. $dD(t)/dt = \delta I(t)$ (Dead; change)

5. $N=S(t)+I(t)+R(t)+D(t)$ (Population; constant)

where $S(t)$ is the number of susceptible individuals who are not infected but could become infected, $I(t)$ is the number of infected individuals who have been infected and are capable of infecting susceptible individuals, $R(t)$ is the number of individuals recovered from the disease, and $D(t)$ is the number of dead individuals among infected individuals. The coefficient β is the infection coefficient (the transmission rate), γ is the

recovery rate (the removal rate for recovered individuals), and δ is the death rate (the fatality rate). N is the population of the community. Infected individuals stay in the community and continue to spread the infection to susceptible individuals until they die. Infected individuals who do not die continue to spread the infection throughout the infection period (recovery period), after which they become recovered individuals.

Formula 3 ($dR(t)/dt$) shows that the number of recovered individuals changes according to the number of infected individuals, and formula 4 ($dD(t)/dt$) shows that the number of deaths also changes according to the number of infected individuals.

Formula 2 ($dI(t)/dt$) is the rate of change in the number of infected individuals, that is, the change in the number of infected individuals per unit time, and it represents the increase/decrease in infected individuals due to contact ($(\beta S(t)I(t))/N$) minus the number of recovered and deceased individuals ($(\gamma + \delta)I(t)$). A higher death rate (fatality rate; δ) (and recovery rate, γ) means that infected individuals are removed more quickly from the 'group of spreaders', that is, 'the number of spreaders decreases more rapidly.' Furthermore, "– $(\gamma+ \delta)$ $I(t)$" indicates that recovered individuals and deceased individuals are removed not only from the disease but also, in the calculation, from the community. However, formula 5 indicates that the population of the community (N), which is used in formulas 1 and 2, is constant.

SIRD models were extended from the SIR model to estimate the number of dead individuals. Conversely, if the change in the number of infected individuals is calculated in cases where deaths occur among the infected individuals, as will be shown later with numerical values in section **5.1. "Changes in the number of infected individuals based on the SIRD model and the flexible compartment model,"** these models indicate that the total number of infected individuals decreases with an increase in the fatality rate, that is, with an increase in the ratio of the number of deaths of infected individuals.

However, for individuals with COVID-19, infected individuals are isolated from the community when they become symptomatic after the latent period ends. Thus, they do not infect susceptible individuals in the community after the latent period. Therefore, the deaths of infected individuals who have been kept in isolation do not indicate a reduction in the number of "spreaders".

The isolated infected individuals recover after the recovery period and then return to the community as the recovered individuals who have immunity. With an increase in the number of recovered individuals in the community, the contact rate between infected individuals and susceptible individuals is reduced by the contact of infected individuals with recovered individuals, causing a decrease in the number of infected individuals.

On the one hand, as is obvious, the deaths of isolated infected individuals reduce the number of recovered individuals returning to the community. Therefore, the death of isolated infected individuals will decrease the "reduction effect on the contact rate between infected individuals and susceptible individuals by recovered individuals (the contact rate reduction effect by recovered individuals)". As a result, when deaths occur among isolated infected individuals, mathematically, the number of infected individuals increases compared to the case where there are no deaths.

On the other hand, the deaths of infected individuals who are not isolated and who remain in the community, whether symptomatic individuals or asymptomatic individuals, reduce the number of spreaders in the same way as in the SIRD model (and/or SEIRD model).

Moreover, the deaths of infected individuals remaining in the community also reduce the number of recovered individuals. This reduction in the number of recovered individuals causes an increase in the contact rate between infected and susceptible individuals compared to when no deaths occur. Therefore, even when infected individuals and recovered individuals remain in the community, deaths can reduce the number of recovered individuals and increase the contact rate between infected and susceptible individuals, potentially causing an increase in the number of infected individuals.

Does the occurrence of deaths among infected individuals lead to a decrease in infections or an increase in infections? Which is correct: "If there are deaths of infected individuals, the total number of infected individuals decreases," or "If deaths occur, worse still, the total number of infected individuals increases"? This is a fundamental question. It is not clear whether the death of infected individuals leads to a decrease in infections or an increase in infections until we calculate this value. The effect of the death of infected individuals on the spread of infection must be examined by calculating the changes in the number of infected individuals when deaths occur.

In this article, using a flexible compartment model specialized for COVID-19, the changes in the number of infected individuals were calculated in the event of death among the infected individuals during the infection process. Therefore, regardless of whether it is a direct cause of death, such as respiratory disease, or an indirect cause of death, such as worsening of underlying conditions or pre-existing diseases, "death of patients during infection", that is, "death of spreaders", is defined as the "death of infected individuals". " The model includes the fatality rate, which indicates the proportion of deceased individuals among infected individuals assigned to the infected individuals kept in isolation and the infected individuals remaining in the community, respectively, as independent variables in the calculation equations. The model also included the symptomatic rate, which controls the ratio of the number of infected individuals being isolated or remaining in the community, as an independent variable in the calculation equation. Therefore, it is possible to perform calculations equivalent to the SIRD model, which assumes that "all infected individuals remain in the community." The changes in the number of infected individuals when deaths occur among them will be calculated for several cases with different symptom rates and for the case with occurrence of reinfection.

2. Framework of the flexible compartment model used here

The flexible compartment model proposed by Ohmori [16] consists of six categories of individuals: 'susceptible (remainder): *RM*'; 'vaccinated: *V*'; 'recovered: *RI, RT, RAS*'; 'infected ('infectious', 'patient'): *P*'; 'isolated: *I, PI*'; and 'death: *DAS, DTI, DT*', as shown in Figure 1. 'Susceptible' refers to susceptible individuals who are not infected but could become infected. 'Vaccinated' refers to vaccinated individuals who have been vaccinated, who have immunity and who live and work in the real community, as shown in Figure 1. 'Recovered' refers to individuals who have recovered from the disease and acquired immunity and live and work in the real community after the infectious period (the recovery period) ends. 'Infected' refers to individuals who have been infected and are capable of infecting susceptible individuals. 'Isolated' refers to individuals kept in isolation, indicating individuals who were isolated and kept in the 'isolation community' until the recovery period (isolation period) ended. After the end of the isolation period, they recover, become immune and return to the community. 'Death' refers to individuals who died from infection after the latent period.

'Back to' indicates "getting back (and/or returning) to susceptible individuals (*RM*) from vaccinated individuals (*V*) after the end of duration (validity period) of vaccine-induced immunity" for vaccinated individuals and/or "getting back (and/or returning) to susceptible individuals (*RM*) from recovered individuals (*RI*, *RT* and *RAS*) after the end of duration (validity period) of infection-induced immunity" for recovered individuals.

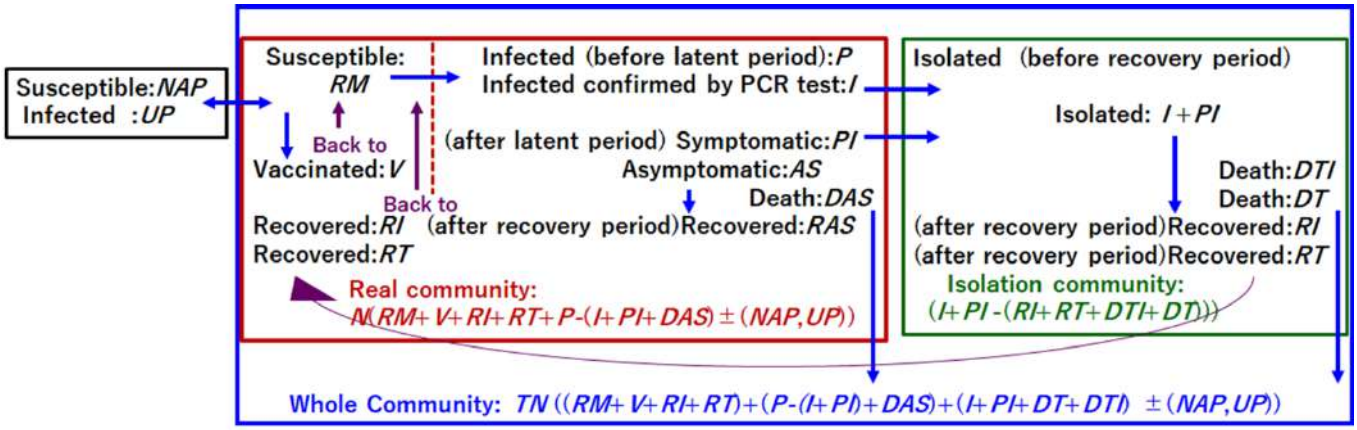

Figure 1: Flow of individuals: 'susceptible; *RM, NAP*', 'vaccinated; *V*', 'recovered; *RI, RT, RAS*', 'infected; *P*(*I, PI, AS*'), *UP*', 'isolated; *I, Pl* and 'death; *DAS, DTI, DT*'. (after Ohmori [16, 17, 18, 19, 20].

The compartment on the left side, containing 'susceptible', 'vaccinated', 'recovered', 'infected' and 'dead (death)', is the 'real community'. Its population, *N*(n), is changed by subtracting the number of isolated individuals (*I, PI*) and dead individuals (*DAS*) and by adding the number of recovered individuals (*RI, RT*). Another compartment on the right side, containing 'isolated', 'recovered' and 'death', is the 'isolation community', whose population, that is, the number of individuals kept in isolation, is also changed by subtracting the number of recovered individuals (*RI, RT*) returning to the real community and of the death (*DTI, DT*). The large compartment consisting of the two compartments mentioned above is the 'whole community', the population of which is referred to as *TN*(*n*). *TN*(*n*) includes the number of individuals living in the two compartments and the toll of death (*DAS, DTI, DT*) occurring at the fatality rate in the two compartments. *TN*(*n*) and *N*(*n*) are changed due to the number of 'susceptible (*NAP*(*n*))' and/or 'infected (*UP*(*n*))' individuals coming in and/or going out of the community. *N*(*n*), the population of the 'Real' community, also changes depending on the number of deaths. As shown above, each compartment contains individuals belonging to different categories, and its population changes by interacting with another compartment and with the outside.

The infected individuals in the community, *P*(*n*), are separated into three groups: those (*I*(*n*)) who were confirmed to be infected because they tested positive, those (*PI*(*n*)) who became symptomatic after the latent period and those (*AS*(*n*)) who were asymptomatic through the recovery period. The isolated individuals are divided into two groups: those (*I*(*n*)) who were confirmed to be infected because they tested positive and were subsequently isolated and those (*PI*(*n*)) who became symptomatic in the community and were subsequently isolated. Each of these parameters needs to be calculated differently depending on the coefficients for the test-positive rate and symptomatic rate.

The recovered individuals, that is, the individuals who were once infected, recovered from disease and have infection-induced immunity, are divided into two groups. One group includes recovered individuals in the right compartment, which are divided into two subgroups: one subgroup comprises those (*RI*(*n*')) who were isolated because they tested positive (*I*(*n*)) but have since recovered, and the other subgroup comprises those (*RT*(*n*')) who were isolated because they were symptomatic in the community (*PI*(*n*)) but have since recovered. The recovered individuals returned to the community after the isolation period ended. The date (*n*') of returning to the community must be calculated in a different manner according to the duration of isolation. The other group includes individuals who recovered from asymptomatic disease in the left compartment (*RAS*(*n*'); they were not isolated, remained in the community and recovered from the disease after the recovery period. Recovered individuals in the real community (*RI*(*n*), *RT*(*n*) and *RAS*(*n*))

reduce the contact rate between infected individuals and susceptible individuals by coming into contact with infected individuals.

Regarding the number of recovered individuals, the following is necessary. That is, the number of recovered individuals is not always equal to the number of isolated individuals. This is because the number of recovered individuals is the number obtained by subtracting the number of deaths from the number of isolated individuals. Specifically, the total number of recovered individuals $RI(n') + RT(n')$ is the number obtained by subtracting the total number of deaths ($DTI(n) + DT(n)$) from the total number of isolated individuals ($I(n) + PI(n)$).

Similarly, the number of recovered individuals who have recovered from asymptomatic infections is also not always equal to the number of asymptomatic infected individuals (AS(n)). This is because the number of recovered individuals is the number after subtracting the number of deaths from the number of asymptomatic infected individuals. Specifically, the total number of recovered individuals ($RAS(n')$) is the number after subtracting the number of deaths ($DAS(n)$) from $AS(n)$.

The dead individuals (Death) who died from infection are also divided into two groups: those ($DAS(n)$) who were asymptomatic and died in the community after the latent period and those ($DTI(n)$ and $DT(n)$) who died during the isolation period. Each of these variables needs to be calculated in a different manner according to the fatality rate. Since the occurrence of death decreases the number of recovered individuals, the occurrence of death results in a reduction in the population ($N(n)$) living in the 'Real' community. The vaccinated individuals $V(n)$ have vaccine-induced immunity and live and work in the community. Vaccination decreases the number of susceptible individuals and reduces the contact rate between infected individuals and susceptible individuals.

The end date of an infection can be thought of as the day when there are no infected individuals (P), or the day when all infected individuals have recovered, or the day when all recovered individuals (R) have returned to the community. In this article, the end date of the infection is defined as the day when the number of infected individuals (P) becomes zero. The duration from the day the infection occurred (day 1) until the end date when the number of infected individuals (P) reached zero, was defined as the "duration of infection". This "duration of infection" may end with a single epidemic (outbreak), but it may also include several epidemics (outbreaks). When the m^{th} day is the day the infection ends, the total number of infected individuals (the final cumulative number of infected individuals; CAP) is given by the value of CAP (m), and the total number of deaths (the final cumulative number of deaths, $CDSUM$) is given by the value of $CDSUM$ (m). Additionally, when recovered individuals do not get back to susceptible individuals, the final number of susceptible individuals (RM) is $RM(m) = TN(m) - CAP(m)$; when recovered individuals get back to susceptible individuals, $RM(m) = TN(m) - CDSUM(m)$. $TN(m)$ is the population of the whole community on day m.

3. Fatality rate

3.1. Fatality rate; "Case fatality rate (CFR)" and "Infection fatality rate (IFR)"

The "fatality rate" indicates the "rate (proportion) of the number of deaths" among individuals infected with a certain disease. This fatality rate is expressed by one of two fatality rates: the "Case Fatality Rate (CFR)" or "Infection Fatality Rate (IFR)".

The "case fatality rate (CFR)" is defined as the "rate of individuals who have died from a disease out of those who have been 'confirmed' to be infected with the disease." The CFR is calculated based on the total number of 'confirmed' infected individuals. On the other hand, the "Infection Fatality Rate (IFR)" is defined as the rate of death among all infected individuals, including asymptomatic and unreported cases. It generally has lower values than the CFR and is said to be "more difficult to measure accurately than the CFR". It should be noted that whether the fatality rate of asymptomatic individuals is low or high is unknown.

Furthermore, regarding the CFR and IFR, since the beginning of the COVID-19 pandemic, that is, in 2020, that the following points have been noted. For example, "Case fatality rate (CFR) = [Number of deaths from disease/Number of diagnosed cases of disease] × 100. It is relevant and important but far from the whole story. The CFR is not the same as the number of actual infections divided by the number of actual deaths from the disease. Not everyone with the infection has symptoms or gets tested, and not everyone who dies from the disease may be recorded as having died from COVID-19. This is because of limited testing, death registration, challenges in determining the cause of death, and more. As a consequence, the CFR is not the same as the average risk of death for infected people." "The key question for understanding the mortality risk of a disease is: If someone is infected with the disease, how likely is it that they will die from it? The answer to that question is captured by the infection fatality rate, which is abbreviated as the IFR. To work out the IFR, we need two numbers: the total number of infections and the total number of deaths from the disease. However, the total number of infections of COVID-19 is not known. One major reason is that not everyone with COVID-19 is tested. Since the total number of infections is not known, the IFR cannot be calculated simply from observed data. But researchers can estimate the total number of infections and deaths and use that to calculate the IFR." And "In order to understand what the case fatality rate can and cannot tell us about a disease outbreak such as COVID-19, it's important to understand why it is difficult to measure and interpret the numbers [21]", and/or "A death in someone who has tested positive becomes progressively less likely to be directly due to COVID-19 as time passes and more likely to be due to another cause. However, there is no agreed cut-off after which COVID-19 can be excluded as a likely cause, and sadly, we know that some people die from their infection many weeks later. Coronavirus can also contribute to a death without being the main or "underlying" cause. The World Health Organization (WHO) recognises this complexity and states that 'A COVID-19 death is defined for surveillance purposes as a death resulting from a clinically compatible illness in a probable or confirmed COVID-19 case, unless there is a clear alternative cause of death that cannot be related to COVID-19 disease (e.g., trauma).' For several months, the COVID-19 Data Dashboard has been reporting, for England, all deaths in people who have a positive

test. This is a robust measure as it uses the fact of a positive test and the fact of death to derive the number reported. However, it is only an approximation of the number of people who die from COVID-19 because other causes of death are included, and some people who die from COVID-19 never had a positive test. It was decided to adopt this measure in April in order to be sure not to underestimate the number of COVID-19-related deaths. It was always intended to review the approach as the pandemic progressed [22].”

In addition, when comparing the fatality rates of different infectious diseases to understand the "seriousness of the damage" of each disease, since the "timing of occurrence of epidemic" differs for each disease, it is appropriate to compare the "fatality rates at the time when each disease was prevalent" rather than the "fatality rates at the same time."

As noted above, the actual calculated fatality rate has issues with accuracy, but as mentioned previously, it should be noted that the purpose of this article is not to estimate the fatality rate but to clarify the effect of deaths among infected individuals on the spreading process of COVID-19.

In this paper, since both the 'number of infected individuals' and the ‘number of deaths’ are calculated based on equations, the number of infected individuals always refers to the number of 'confirmed infected individuals’, and the number of ‘deaths’ also always refers to the number of 'confirmed deaths.' Therefore, the “fatality rate” corresponds to both the “case fatality rate” (CFR), the fatality rate among confirmed infected individuals, and the “infection fatality rate” (IFR), the fatality rate among the total infected individuals. In addition, from a mathematical point of view, it does not matter whether a "death of an infected individual" is a direct death from COVID-19 (death from respiratory illness) or an indirect death (death due to worsening of pre-existing conditions). Regardless of the cause of death, the "deaths of infected individuals" signify a decrease in the number of 'spreaders' and a decrease in the number of recovered individuals.

Furthermore, in this article, two types of fatality rates are used: the fatality rate of isolated individuals, '$frI(n)$', and the fatality rate of asymptomatic individuals, '$fr(n)$'. It should be noted that the 'fatality rate of asymptomatic infected individuals' is, in practice, used for calculations as 'the fatality rate of infected individuals living in the community without isolation,' regardless of whether they have symptoms or are asymptomatic.

In this article, all the independent variables, including the infectious capacity for coronavirus, symptomatic rate, and fatality rate, as well as the latent period and recovery periods, are used as "average values." For example, in calculations, if deaths occur, the infected individuals who are considered to die will die before the end of the recovery period. In the model of this article, the average day of death is set as the "midpoint day between the end of the latent period and the end of the recovery period." Specifically, as explained later in section **4.2. “Calculation of the number of infected individuals, the number of individuals newly infected a day, the number of recovered individuals and the population of the real community”**, some of the infected individuals who were isolated on day n die on day (n + trunc ((rp-lp)/2)). The “rp” is the recovery period, and the “lp” is the latent period. For asymptomatic infected individuals who are not isolated but who stay in the community, the same procedure is used. Namely, in the case of asymptomatic infected individuals who were infected on day n, some of them die on the same day (n+trunc((rp-lp)/2)).

3.2. Trends in the ‘observed fatality rate’

The novel coronavirus disease that occurred in 2019 was reported in more than 100 countries and regions by the end of March 2020, becoming the first “epidemic (outbreak) worldwide”. This is the first “pandemic of' COVID-19” declared by the WHO on March 11, 2020, as saying "We have therefore made the assessment that COVID-19 can be characterized as a pandemic [23]”.

The fatality rate (case fatality rate) has been noted since the beginning of the epidemic/pandemic of COVID-19, and its value has varied depending on location and time. For example, the "Report of the WHO-China Joint Mission on Coronavirus Disease 2019 (COVID-19), in February 2020" was the earliest scientific and organized report on the COVID-19 infection situation, and regarding this, the following views have been stated; "(Based on the first published in the Report), in the earliest stages of the outbreak, the CFR was much higher: it was 17.3% across China as a whole and greater than 20% in the center of the outbreak, in Wuhan. But in the following weeks, the CFR declined. By 1st February, the CFR in Wuhan was still 5.8%, while it was 0.7% across the rest of China. The CFR was different in different places [21]”, and/or “The case fatality rate (CFR) was reported to be 15% (six of 41 patients) in the initial period, but this estimate was calculated from a small cohort of hospitalised patients. Subsequently, with more data emerging, the CFR decreased to between 4.3% and 11.0% and later to 3.4%. The rate reported outside China in February 2020 was even lower (0.4%; two of 464) [24].”

Furthermore, regarding deaths from COVID-19, discussions have been held about 'risk factors for COVID-19 death (factors contributing to death from COVID-19)' while referring to the fatality rate.

For example, “(All COVID-19 cases reported through February 11, 2020, were extracted from China’s Infectious Disease Information System), A total of 1,023 deaths has occurred among 44,672 confirmed cases for an overall case fatality rate of 2.3%. Additionally, these 1,023 deaths occurred during 661,609 PD (person-days) of observed time, for a mortality rate of 0.015/10 PD. The ≥80 age group had the highest ‘case fatality rate’ of all age groups at 14.8%. Case fatality rate for males was 2.8% and for females was 1.7%. By occupation, patients who reported being retirees had the highest case fatality rate at 5.1%, and patients in Hubei Province had a >7-fold higher case fatality rate at 2.9% compared to patients in other provinces (0.4%). While patients who reported no comorbid conditions had a case fatality rate of 0.9%, patients with comorbid conditions had much higher rates—10.5% for those with cardiovascular disease, 7.3% for diabetes, 6.3% for chronic respiratory disease, 6.0% for hypertension, and 5.6% for cancer. Case fatality rate was also very high for cases categorized as critical at 49.0% [25]”, and/or “(The cross-sectional study design was implemented to extract all COVID-19-positive patients who had a definite outcome from the open-access individual-level data (confirmed cases from December 1, 2019, to February 5, 2020) reported by Xu et al. on April 21st, 2020), A total of 828 confirmed cases of COVID-19 with definite outcomes were retrospectively identified from open

access individual-level worldwide data. Based on the data, older age (adjusted odds ratio (aOR), 1.079), males (aOR, 1.607), patients with hypertension (aOR, 3.576), diabetes mellitus (aOR, 12.234), and patients located in America (aOR, 7.441) were identified as the risk factors of mortality among COVID-19 patients [26]", and/or "(Electronic database were systematically searched till 31 August 2020. Based on the meta-analysis of 42 studies and 423,117 patients), The findings of the included studies were consistent in stating the contribution of comorbidities, gender, age, smoking status, obesity, acute kidney injury, and D-dimer as a risk factor to increase the requirement for advanced medical care. The analysis results showed that the pooled prevalence of mortality among hospitalized patients with COVID-19 was 17.62% (42 studies and 423,117 patients). Older age has shown increased risk of mortality due to coronavirus, and the pooled odds ratio (pOR) and hazard ratio (pHR) were 2.61 and 1.31, respectively. A significant association was found between COVID-19 mortality and male (pOR = 1.45; pHR = 1.24), and current smoker (pOR = 1.42). Furthermore, risk of mortality among hospitalized COVID-19 patients is highly influenced by patients with Chronic Obstructive Pulmonary Disease (COPD), Cardiovascular Disease (CVD), diabetes, hypertension, obese, cancer, acute kidney injury and increase D-dimer [27]", and/or "(Based on the epidemiological studies on the CFR of COVID-19 published between January 1, 2020, and March 31, 2023), There were variations in the CFRs (case fatality rates) among different variants of COVID-19 (Alpha: 2.62%, Beta: 4.19%, Gamma: 3.60%, Delta: 2.01%, Omicron: 0.70%), and disparities in CFRs also existed among continents. On the whole, the CFRs of COVID-19 in Europe and Oceania were slightly lower than those in other continents. There was a statistically significant association between the variant, HDI (Human Development Index) value, age distribution, coverage of full vaccination of cases, and the CFR [28]", and/or "(Using the public data from the WHO to calculate and compare the COVID-19 infection and case fatality rates on different continents and at different income levels from 2019 to 2023), The Global prevalence of COVID-19 increased from 0.011 to 0.098, while case fatality rates declined from 0.024 to 0.009 from 2019 to 2023. Europe reported the highest cumulative infection rate (0.326), with Africa showing the lowest (0.011). Conversely, Africa experienced the highest cumulative case fatality rates (0.020), with Oceania the lowest (0.002). Infection rates in Asia showed a steady increase in contrast to those in other continents which observed initial rises followed by decreases. A correlation between economic status and infection rates was identified; high-income countries had the highest cumulative infection rate (0.353) and lowest case fatality rate (0.006). Low-income countries showed low cumulative infection rates (0.006) but the highest case fatality rate (0.016). Initially, high and upper-middle-income countries experienced elevated initial infection and case fatality rates, which subsequently underwent significant reductions [29]", and/or "(Based on the observational study included all Austrian residents and covered the time from February 2020 to May 2023, examining CFRs overall, monthly, and during dominant SARS-CoV-2 variant periods), The overall CFR of 30-day COVID-19 mortality was 0.31% but varied depending on month, with the highest being 5.9% in April 2020 and the lowest 0.07% in January 2022. The variant periods reflected this trend of decreasing CFR, with the highest for Wuhan-Hu-1 (2.05%) and the lowest for BA.1 (0.08%). Overall CFRs were particularly high in the group without any previous immunizing event (0.67%), the elderly (85 + year group: 7.88%) and in nursing home residents (7.92%). Nursing home residents accounted for 30.82% of all COVID-19 deaths while representing only 1.22% of diagnosed infections. Total SARS-CoV-2 infections were estimated to be almost double than confirmed cases with a corresponding overall IFR of 0.16% [30]", and/or "(Based on the case fatality ratio (CFR) and mortality per 100,000 population in the countries mentioned in the database of Johns Hopkins University & Medicine. Coronavirus resource center, updated on March 16, 2023), The following mortality rates were reported in terms of CFR: Canada (same as the US) with 1.1%, followed by Spain, Italy, Germany, France, Austria, Japan, Australia, and South Korea with respective rates of 0.9%, 0.7%, 0.4%, 0.4%, and 0.4%, 0.2%, 0.2%, and 0.1%, respectively. In comparison with that in other countries in the group, the fatality rate was highest in the US along with Canada. Japan had the second lowest mortality rate, the same as that in Australia. Japan's CFR was lower than that of other parts of the world due to several positive social (public awareness), economic (healthcare spending), and infrastructure (vaccination drive) factors, among others [31]", and/or "(All serological samples were collected between May and November 2020; We studied this association across the French departments using 82,467 serological samples and a hierarchical Bayesian model with spatial smoothing), The analyses were adjusted for intensive care beds per capita, age of the population, and diabetes prevalence (as a surrogate for obesity). We found that increasing departmental incidence from 3 to 9% rose IFR from 0.42 to 1.14%, and IHR from 1.66 to 3.61%. An increase in incidence from 6 to 12% in people under 60 was associated with an increased proportion of people over 60 among those infected, from 11.6 to 17.4%. Higher incidence increased the risk of death for infected individuals and their risk of hospitalization by the same magnitude. These findings could be explained by a higher age among infected individuals in high-incidence areas, rather by than hospital overload [32]", and/or "(Regarding the dataset includes 2875 samples collected from Mashhad hospitals between March 2020 and March 2021), Age emerges as the most significant predictor of COVID-19 patient recovery or mortality, with higher ages generally contributing to higher SHAP (SHapley Additive exPlanations) values, indicating an increased model output, while younger ages tend to decrease it. The presence of a ventilator also strongly influences prediction. Additionally, Cough, followed by Apnea and Carcinoma are notable factors. Features such as Test-Result and Conformation-Method, and then Healthcare staff and ICU_hospitalization, appear to have a smaller influence on the model's predictions, as indicated by the concentration of points around zero [33]."

As shown above, according to the trends in the fatality rate, the fatality rate has changed depending on the country, region and year, reflecting changes in the occurrence of variants and in medical conditions (such as public health, medical care, pharmaceuticals, and vaccination status). Although the fatality rate varies by region, it can be said that, in all regions, the fatality rate has decreased with the widespread and expanded implementation of medical care and preventive measures. In particular, since 2022, when mass vaccinations became widely conducted, the fatality rate, which exceeded 10% in the early stages of the pandemic, has fallen to approximately 1%. The "with corona (coexisting with COVID-19)" policy and the "COVID-Zero strategy" could not have been implemented without vaccination. However, it should be noted that even in 2025, the fatality rate of COVID-19 will remain in the range of approximately 0.1% to over 1.0%, and COVID-19 is an

infectious disease that could cause many deaths if outbreaks occur [34].

4. Calculation process of the flexible compartment model

4.1. Contact rate in the community mixed with infected, susceptible, recovered and vaccinated individuals

Infection can be caused by contact between infected individuals and susceptible individuals. It actually occurs in a community mixed with infected, susceptible and recovered individuals. Thus, infected individuals contact not only susceptible individuals but also recovered individuals. From a physical point of view, contact between infected individuals and recovered individuals must reduce the contact rate between infected individuals and susceptible individuals when the number of recovered individuals increases. Accounting for the reduction effect of recovered individuals on the contact rate, the contact rate should be given by the following equation:

$$cr(n)=(S(n)/N(n))(1-\delta*(R(n)/N(n))) \quad (1)$$

where '$cr(n)$' is the contact rate, n is the number of days since the first day (1 day) when the infection began, $S(n)$ is the number of susceptible individuals in the community, $R(n)$ is the number of recovered individuals who returned to the community from isolation, and $N(n)$ is the current population that includes susceptible individuals, vaccinated individuals, infected individuals who are not yet isolated and recovered individuals who returned to the real community from the isolation community but excludes individuals who are kept in isolation and dead individuals. The term '- ($R(n)/N$ (n))' represents the reduction effect of recovered individuals on the contact rate between infected individuals and susceptible individuals, and the term '$1-\delta(R(n)/N(n)$' represents the 'reduction rate' of the contact rate. The reduction effect increases with decreasing value of (1-δ(R(n)/N(n)). That is, when the number of recovered individuals is 0, the value of (1-δ(R(n)/N(n)) is 1, indicating the maximum, and the contact rate decreases as the number of recovered individuals increases. 'δ' is a coefficient that expresses the activity level of the recovered individuals living in the community. When the value of δ is given by 1, the activity is the same as that of the susceptible individuals, and when the value of δ is given by 0, the recovered individuals are not active, meaning a similar condition as they are kept in isolation, although the number of recovered individuals is added to the population.

The reduction in the contact rate is caused not only by the recovered individuals but also by the vaccinated individuals who have been vaccinated, have immunity and are living and working in the community. The reduction effect of vaccination should be taken into account in the simulation, as expressed by Eq. (1'):

$$cr(n) =(S(n)/N(n))* (1-(alI(n)* CRT(n)+alV(n)*V(n))/N(n)) \quad (1')$$

where $CRT(n) =\Sigma RT(n)$ and $RT(n)$ is the number of recovered individuals who were once isolated because they were symptomatic and had returned to the community when the isolation period ended and where the coefficient alI (n) is the activity level of the recovered individuals who returned to the community from isolation. $V(n)$ is the number of vaccinated individuals who have immunity and are living and working in the community, and alV (n) is the activity level of the vaccinated individuals. The '(alI(n)* $CRT(n)$+alV(n)*$V(n)$)' conceptually refers to the sum of the activities of recovered individuals and vaccinated individuals, and '(1-($alI(n)$* $CRT(n)$+$alV(n)$*$V(n)$)' is equivalent to (1-$\delta(R(n))$ of Eq. (1). The contact rate, $cr(n)$, expressed in Eq. (1'), is used for the calculation of the number of infected individuals, as shown by Eq. (2). In addition, the contact rate in Eq. (2) reflects the contact rate reduction effect of all the recovered individuals, including not only the individuals who were once isolated and had returned to the community but also the individuals who had recovered from asymptomatic individuals and were living in the community. The contact rate decreases with increasing trial time (days) because of an increase in the sum of the number of recovered individuals and the number of vaccinated individuals, $R+V$.

4.2. Calculation of the number of infected individuals, the number of individuals newly infected a day, the number of recovered individuals and the population of the real community

First, in Ohmori's papers that do not deal with deaths (fatality rate) (for example, Ohmori (2025) [20]), for some variables, when they became very small values below the decimal point, they were set to 0, and the calculations proceeded. For example, when the value of the variable AP fell below four decimal places, the value of the variable AP was set to 0.0, and the calculation was continued. However, the fatality rate is generally low, usually less than a few percent; for example, 0.05 (5%) or 0.01 (1%) or even lower. In this article, to address this small fatality rate, the calculation uses the decimal values as they are.

Next, note that the number of infected individuals $P(n)$ should not be equal to the number of individuals infected each day $AP(n)$, which is usually announced. The former is the total number of infected individuals existing in the community, that is, the sum of the number of infected individuals during the latent period and/or the recovery period, whereas the latter is the number of individuals newly infected for one day. However, P (1), the initial number of infected individuals, is arbitrarily set for simulation. The increment and/or decrement in the number of infected individuals on date n in the community, $\Delta P(n)$, can be calculated by subtracting the number of individuals isolated on date n from the number of individuals newly infected on date n.

For the simulation, an Excel file is used, and the calculation is performed via Eq. (2). The Excel files and the meanings of the individual terms/variables are explained in the supplementary files. The independent variables of 24 terms can be specified arbitrarily, and the values of the dependent variables of 103 terms are uniquely determined based on the independent variables whose values are given arbitrarily.

The number of individuals who are newly infected on day n, $AP(n)$, that is, the number of new infected individuals at night on day n, $AP(n$(night)), is given by the following equation:

$$AP(n)=AP(n(\text{night}))=(pfc(n)/lp(n))*icf(n)*cr(n)*(RP(n)/N(n))*RM(n)=(pfc(n)/lp(n))*icf(n)*(RM(n)/N(n))*(1(alI(n)*(CRI(n)+CRT(n))+al(n)*CRAS(n)+alV(n)*V(n))/N(n))*(RP(n)/N(n))*RM(n) \quad (2)$$

where the coefficient $pfc(n)$ is the potential (biological) infectious capacity of coronavirus (the infectivity coefficient), which is an approximate value indicating the number of

susceptible individuals infected during the latent period, *lp*(*n*). The latent period, *lp*(*n*), is the time interval between when an individual is infected and when he/she is symptomatic. '*pfc*(*n*)/*lp*(*n*)' is the number of susceptible individuals infected by an infected individual a day, and its value, including decimal places, is used in the calculation. The coefficient *icf*(*n*) is the "infection reduction rate" reduced by infection control measures preventing the spread of the virus, such as facemasks, partitions and disinfectants.

The coefficient '*cr*(*n*)' is the contact rate, and instead of Eq. (1'), it is realistically given by

$$cr(n) = (RM(n)/N(n))* (1-(alI(n)*(CRI(n)+CRT(n))+al(n)*CRAS(n)+alV(n)*V(n))/N(n)) \quad (1'')$$

The coefficient *alI* (*n*) is the activity level of the recovered individuals *CRI*(*n*)+*CRT*(*n*) who returned from isolation to the community, where *CRI*(*n*) is the Σ*RI*(*n*) and RI(n) is the number of recovered individuals who were isolated due to being test positive and had returned to the community and *CRT*(*n*) is the Σ*RT*(*n*) and *RT*(*n*) is the number of recovered individuals who were once isolated due to being symptomatic and had returned to the community; these show all the recovered individuals who returned from isolation to the community. The coefficient *al*(*n*) is the activity level of the recovered individuals, *CRAS*(*n*), who have recovered from the asymptomatic individuals and are living in the community. *CRAS*(*n*) is Σ*RAS*(*n*), and *RAS*(*n*) is the number of recovered individuals who were infected but were not symptomatic, were asymptomatic, were not isolated, were staying in the community, had continued to infect until the recovery period ended and then became 'recovered individuals.' *alV*(*n*) is the activity level of the individuals *V*(*n*) who were vaccinated. The term '*alI*(*n*)*(*CRI*(*n*) +*CRT*(*n*)) +*al*(*n*)*CRAS*(*n*)' is equivalent to *CRT*(*n*) in Eq. (1'), and '1-(alI(*n*)*(*CRI*(*n*)+*CRT*(*n*))+*al*(*n*)*CRAS*(*n*) +*alV*(*n*)*V(*n*))' is equivalent to '1-*δ*(*R*(*n*)' in Eq. (1).

In a strict sense, in the model, since an infection occurs during the day from morning to evening, for the purpose of calculation, the value of AP(n) at night, AP(n(night)), is the correct number of individuals newly infected a day. This number increases/decreases from the *AP*(*n*) in the morning, which is equal to the *AP*(*n*) of the previous night, that is, *AP*(*n*-1(night)).

RM(*n*) means the "Remainders", whose meaning is the 'remaining number subtracting the number of infected individuals from the community population', and corresponds to the number of susceptible individuals (*S*(*n*)) in Eqs. (1) and (1'). As its strict calculation process is explained in section **4.4. "Change in the number of susceptible individuals"**, the number of susceptible individuals (*RM*(*n*)) is calculated not only by subtracting from the total population *TN* of the community the cumulative number *CAP* of infected individuals, including both recovered individuals and dead individuals, the cumulative number *CI* of individuals who were confirmed to be infected due to being test positive and then were isolated, and the cumulative number *V* of vaccinated individuals but also by adding the total cumulative number of susceptible individuals who got back from recovered individuals (*JCReRec*(*n*)). This total of the cumulative number of susceptible individuals who get back from recovered individuals (*JCReRec*(*n*)) is explained by Eq. (38) in section **4.3. "Change in the number of individuals getting back to susceptible individuals from recovered individuals."** Therefore, the number of susceptible individuals (*RM*(*n*) in the community at night (after the occurrence of 'breakthrough infection' and/or 'reinfection') is given by

$$RM(n)= TN(n)-(CI(n)+CAP(n)+V(n))+JCReRec(n)+CTAPReRec(n-1) \quad (3)$$

where *TN*(*n*) is the total population of the whole community, such as a city. *TN* (1) is the initial population of the community arbitrarily given in the simulation, and *TN*(*n*) is changed by coming in/going out of the susceptible individuals *NAP*(*n*) and/or the infected individuals *UP*(*n*).

CI(*n*)=Σ*I*(*n*), where *I*(*n*) is the number of individuals isolated because they test positive. Since all the individuals confirmed to be infected due to test positivity are not always isolated and the individuals who have been decided to be isolated are isolated on the day next to the day when they are confirmed to be infected, in the actual calculation, *I*(*n*) is given by:

$$I(n)= CP(n-1)* i(n-1) \quad (4)$$

where the coefficient *i*(*n*) is the isolation rate for individuals who are confirmed to be infected because they test positive. *CP*(*n*) is the number of individuals confirmed to be infected because they tested positive. The individuals who are required to be isolated are isolated the following day for the purpose of calculation.

Conversely, the individuals confirmed to be infected on the previous day, date (*n*-1), are isolated on date n. Thus, *I*(*n*) is given by Eq. (4). *CP*(*n*) is given by:

$$CP(n)=T(n)*bp(n)*ir(n) \quad (5)$$

where *T*(*n*) is the number of individuals who underwent PCR and/or antibody testing, which can be set arbitrarily on any day when tests are performed, and the coefficient *bp*(*n*) is the magnification of the incidence rate for the test to the incidence rate, *ir*(*n*), in the community.

The incidence rate, ir(n), in the community is given by:

$$ir(n)=P(n)/TN(n) \quad (6)$$

where *P*(*n*) is the number of infected individuals already living in the community and *P* (1) is the initial number of infected individuals in the community and is arbitrarily given by you. *TN*(*n*) is the total population of the whole community. Since individuals who have the test are mainly close contacts, the incidence rate for the test would be biased to be higher than *ir*(*n*). The incidence rate for the test is given by the magnification with respect to *ir*(*n*). The value of *bp*(*n*)*ir*(*n*) indicates the percentage of positive results for the PCR and/or antibody test, that is, the 'positive rate' in the test, *tir*(*n*). The positive rate, *tir*(*n*), is given by:

$$tir(n)=bp(n)*ir(n) \quad (7)$$

CAP(*n*) is the cumulative number of individuals newly infected a day up to the morning of date *n*; this value is equal to the cumulative number of infected individuals up to the night date (*n*-1). *CAP*(*n*) includes the number of individuals who were

$$CAP(n) =ΣAP(n) \quad (8)$$

In this article, as previously noted (in section **2. "Framework of the flexible compartment model used here"**), since the day when the number of infected individuals (*P*) becomes zero is defined as the end day of the infection, the total number of

infected individuals is given by $CAP(n)$ on the day when $P(n)$ becomes zero, that is, the day when $P(n) = 0$.
$V(n)$ in Eq. (3) is the number of vaccinated individuals on date n, which represents the cumulative number of currently existing vaccinated individuals, excluding individuals who have got back to susceptible individuals.

$$V(n) = JCV0(n)\text{-}CReVac(n) \qquad (9)$$

where $CReVac(n)$ is $\Sigma ReVac(n)$, and $ReVac(n)$ is the number of individuals who have got back from vaccinated individuals to susceptible individuals on date n, $JCV0(n)$ is the 'adjusted $CV0(n)$', and $CV0(n)$ is the cumulative (total) number of vaccinated individuals up to day n:

$$CV0(n)=\Sigma V0(n)= \Sigma(TN(1)*vd(n)) \qquad (10)$$

Eq. (9) indicates that the number of currently existing vaccinated individuals ($V(n)$) is calculated by subtracting the number of individuals who have got back to susceptible individuals ($CReVac(n)$) from the (adjusted) total number of vaccinated individuals ($JCV0(n)$). $JCV0(n)$ is calculated as follows:

$$JCV0(n)=\text{IF}(CV0(n)< (TN(n) +RM00(n)), (TN(n) +RM00(n)), (TN(n) +RM00(n))) \qquad (11)$$

where $RM00(n)$ is the number of currently existing susceptible individuals in the community and is given by:

$$RM00(\text{n})= TN(n)+JCReRec(n)\text{-}(CI(n)+CAP(n)) \ (=(TN(n)\text{-}(CI(n)+CAP(n))) +JCReRec(n)) \qquad (12)$$

where $TN(n)$ is the total population of the community and $JCReRec(n)$ is the cumulative number of susceptible individuals who got back from recovered individuals, excluding the number of individuals who were reinfected; that is, the number of currently existing susceptible individuals who got back from recovered individuals is given by Eq. (38). $CI(n)$ is the cumulative number of individuals isolated because they tested positive, and $CAP(n)$ is the cumulative number of individuals up to the nth day, including the number of individuals who tested positive but were not isolated and were staying in the community. Eq. (12) represents the sum of the number of 'remaining original' susceptible individuals ($TN(\text{n})$-($CI(n)+CAP(n)$)) and the number of currently existing susceptible individuals who got back from recovered individuals ($JCReRec(n)$).

The total number of currently existing vaccinated individuals ($CV0(\text{n})$) must be less than or equal to the total number of the community's population ($TN(n)$) and the number of susceptible individuals in the community ($RM00(\text{n})$). Specifically, ($TN(n)+RM00(n)\text{-}CV0(n)$) should be greater than or equal to 0; that is, ($TN(n)+RM00(n)\text{-}CV0(n)$)≧0. Thus, $CV0(n)$ should be less than or equal to the value of ($TN(n)+RM00(n)$); that is, $CV0(n)$)≦($TN(n) +RM00(n)$). Therefore, if $CV0(n)$ calculated via Eq. (10) becomes larger than ($TN(\text{n}) +RM00(n)$), $CV0(n)$ should be set to ($TN(n) +RM00(n)$); otherwise, $CV0(n)$ is given by Eq. (10). In other words, Formula (11) indicates that:

If $CV0(n) < (TN(n) +RM00(n))$, then $JCV0\ (n)= CV0\ (n)$; otherwise, $JCV0(n)= (TN(n) +RM00(n))$'
$RP(n)$ in Eq. (2), "Remaining Patients", refers to the number of infected individuals living and working in the community, that is, the number of infected individuals in the community excluding the infected individuals kept in isolation and the dead individuals. In other words, $RP\ (n)$ is the total number of infected individuals during the latent period and asymptomatic infected individuals who are not isolated but who stay in the community even after the latent period. Thus, $RP(n)$ could be called the 'Spreader' who continues to infect susceptible individuals in the community. When n is 1, which indicates the first day of simulation, $RP\ (1)$ is equal to $P\ (1)$, which is the initial number of infected individuals in the community and is arbitrarily given by you. Since $P(n)$ is the number of infected individuals remaining in the community and is calculated by summing the number of infected individuals, which is calculated as the number of infected individuals $AP(n)$ minus the number of isolated individuals ($PI(n)$), the number of dead individuals ($DAS(n)$) and the number of recovered individuals in the community ($RAS(n)$), $P(n)$ is expressed with the following equation:

$$P(n)=\Sigma(AP(n)\text{-}PI(n\text{-}1)\text{-}DAS(n\text{-}1)\text{-}RAS(n)) = \Sigma AP(n)\text{-}\ \Sigma PI(n\text{-}1)\text{-}\ \Sigma DAS(n\text{-}1)\text{-}\ \Sigma RAS(n) \qquad (13)$$

where $\Sigma AP(n)$ is $CAP(n)$ and $PI\ (n)$ is the number of symptomatic individuals who became symptomatic on the day after the end of the latent period in the real community and were isolated the next day. $PI(n)$ is given by:

$$PI(n)= AP(n\text{-}(lp+1))* syr(n\text{-}(lp+1)) \qquad (14)$$

where $lp(n)$ is the latent period and $(n\text{-}(lp+1))$ indicates the 'latent period+1' before date n, meaning the day after the end of the latent period, because the infected individuals become symptomatic and are isolated on the day after the end of the latent period. The value of $AP(\text{n}\text{-}(lp+1))$ is the number of infected individuals a day on day $(n\text{-}(lp+1))$, which is the day after the end of the latent period. The coefficient $syr\ (n)$ is the symptomatic rate on day n. When $syr\ (n)$ is 1, all the infected individuals become symptomatic and isolated.
Conversely, therefore, the number of asymptomatic infected individuals, $AS(n)$, is given by

$$AS(n) = AP(n\text{-}(lp+1)) - PI(n) \qquad (15)$$

$DAS(n)$ is the number of individuals who are asymptomatic and die of infection after the latent period in the community, that is, the death toll in the community. It is given by:

$$DAS(n)= AS(n\text{-trunc}((rp\text{-}lp)/2))*fr(n\text{-trunc}((rp\text{-}lp)/2)) \qquad (16)$$

where the coefficient $rp(n)$ is the recovery period, which is the time interval between when an individual is infected and when he/she recovers from the disease and is not capable of infection. The value of '$(rp\text{-}lp)$' is equivalent to the isolation period. $AS(n\text{-trunc}((rp\text{-}lp)/2))$ is the number of asymptomatic infected individuals who were not isolated and who were remaining in the community on the day 'trunc$((rp\text{-}lp)/2)$ days' before day n. This $AS(n)$ is the number of infected individuals given by subtracting the PI from the AP, as shown by Eq. (15). The coefficient $fr(n)$ is the fatality rate for asymptomatic infected individuals in the community. The 'death' of infected individuals occurs in the middle of the isolation period; that is, 'trunc$((rp\text{-}lp)/2)$'. Specifically, some of the infected individuals who were isolated on day n die on day $(n+\text{trunc}((rp\text{-}lp)/2))$. For asymptomatic individuals, the same procedure was used. Namely, an $AS(n)* fr(n)$ number of individuals will also die on day $(n+\text{trunc}((rp\text{-}lp)/2))$. Specifically, when a part of them develops symptoms and is isolated on day n, out of the

remaining asymptomatic individuals $AS(n)$, the number $AS(n) * fr(n)$ will die on day $(n + \text{trunc}((rp - lp)/2))$.

For example, in the case of lp=5 and rp=14, when it is found that the individuals who were infected on the first day do not develop symptoms even the day after the latent period ends (6th day), they are then determined to be 'asymptomatic individuals' on the following day (7*th* day), and, four days later (trunc(14-5=trunc(9/2)=4 days), that is, on the 11th day (10 days after infection), it is calculated that they will die. Conversely, the death toll of asymptomatic individuals on date n, $DAS(n)$, is given by Eq. (16).

$RAS(n)$ is the number of recovered individuals who were infected but were asymptomatic and not isolated; these individuals continued to infect susceptible individuals in the community until the recovery period ended, after which they became recovered individuals. In the actual calculation, $RAS(n)$ is the number of asymptomatic infected individuals excluding the death toll, and it is given by:

$$RAS(n)=AS(n-(rp-lp))-DAS(n-(1+\text{trunc}((rp-lp)/2))) = AS(n-(rp-lp))-AS(n-(rp-lp))*fr(n-(rp-lp)) \quad (17)$$

$CRI(n)$ in Eq. (1'') is ΣRI(n), where RI(n) is the number of recovered individuals who were isolated because they tested positive.
$RI(n)$ is given by:

$$RI(n)=I(n-rpI)-DTI(n-(1+\text{trunc}(rpI/2))) \quad (18)$$

where $I(n)$ is the number of isolated individuals who tested positive, and it is given by Eq. (4).
$DTI(n)$ is the death toll among individuals isolated because they test positive and is given by:

$$DTI(n)= I(n-\text{trunc}(rpI/2))*frI(n-\text{trunc}(rpI/2)) \quad (19)$$

where $frI(n)$ is the fatality rate for the isolated individuals and $rpI(n)$ is the isolation period for the isolated individual due to a positive test result, which is less than or equal to rp. The deaths of isolated individuals occurred during the middle of the isolation period. When the number of individuals isolated on day n is $I(n)$, $I(n)* frI(n)$, the number of individuals will die on the $(n+\text{trunc}(rpI/2))$th day. Conversely, the death toll on day n, $DTI(n)$, is the number of death among the individuals who were isolated on day $(n-\text{trunc}(rpI/2))$ and is given by Eq. (19).

$CRT(n) = \Sigma RT(n)$, where $RT(n)$ is the number of recovered individuals who were isolated because they developed symptoms in the community. $RT(n)$ is given by

$$RT(n)=PI(n-(rp-lp))-DT(n-(1+\text{trunc}((rp-lp)/2))) \quad (20)$$

where $DT(n)$ is the death toll among the individuals isolated due to being symptomatic and is given by Eq. (21); '$(n-(rp-lp))$' indicates the time lag in days between the 'nth day' and 'isolation'; and '$(n-(1+\text{trunc}((rp-lp)/2)))$' indicates the time lag in days between the 'nth day' and the 'death date'.

$$DT(n)=PI(n-\text{trunc}((rp-lp)/2))*frI(n-\text{trunc}((rp-lp)/2)) \quad (21)$$

where PI (n) is the number of symptomatic infected individuals given by Eq. (14) and $frI(n)$ is the fatality rate for the isolated individuals. '$(rp-lp)$' is the isolation period for the individuals isolated because they are symptomatic.

For example, when lp = 5 and rp = 14, individuals who become infected on day 1 will develop symptoms the day after the end of the latent period (day 6), will be isolated the following day (day 7), and will die in the middle of the isolation period, 4 days later (trunc(14-5) = trunc(9/2) = 4 days), that is, on day 11 (10 days after infection).
For calculation, Eq. (2) is transformed into the following equation:

$$AP(n(\text{night}))= p(n)* RM(n) \quad (22)$$

where $p(n)$ is the infection coefficient, which is the infectious capacity and includes the contact rate that changes with the number of susceptible individuals, infected individuals, recovered individuals and vaccinated individuals in the (real) community:

$$p(n)= (pfc(n)/lp(n)) * icf(n) *(RM(n)/N(n))* (1-(AL(n)/N(n)))*(RP(n)/N(n)) \quad (23)$$

where $AL(n)$ is the sum of the activity levels of the recovered individuals and vaccinated individuals:

$$AL(n)=alI(n)*(CRI(n)+CRT(n))+al(n)*CRAS(n)+alV(n)*V(n) \quad (24)$$

The term $AL(n)/N(n)$ is equivalent to the term $\delta(R(n)/N(n))$, and the term '$1-(AL(n)/N(n))$' is equivalent to the term $(1-\delta(R(n)/N(n))$ of Eq. (1). When the value of $alI(n)$ is given a value of 1, the activity of recovered individuals who returned from isolation to the community is the same as that of the susceptible individuals, and when the value of $alI(n)$ is given a value of 0, the recovered individuals are not active, meaning a similar condition as they are kept in isolation, although the number of recovered individuals who returned to the community is added to the population. For $al(n)$ and $alV(n)$, similar things can be said. When the value of $AL(n)$ is 1, the activity of recovered individuals and vaccinated individuals is the same as that of susceptible individuals. If the value of $AL(n)$ is 0, neither the recovered individuals nor the vaccinated individuals are active. This means that the community resembles a situation consisting only of infected and susceptible individuals, although the number of recovered individuals who have returned to the community and of vaccinated individuals is added to the population.

The value of $pfc(n)/lp(n)$ is the infection rate (persons/person/day) for an infected individual, and $(RP(n)/N(n)$ indicates the ratio of the number of infected individuals living in the community. Thus, the value of $(pfc(n)/lp(n)) * (RP(n)/N(n))$ indicates the probability of occurrence of infection by the total number of infected individuals in the community. The term $(RM(n)/N(n)) * (1-(AL(n)/N(n)))$ indicates the contact rate, that is, the probability of contact occurring between susceptible individuals and an infected individual. Therefore, the coefficient $p(n)$ indicates the possibility of infection of susceptible individuals per day in the community with mixed infected, susceptible, recovered and vaccinated individuals.

The number of infected individuals in the morning on day n, $P(n)$, is given by the following equation:

$$P(n)= P(n\text{-}1(\text{night}))=RP(n\text{-}1)+AP(n\text{-}1(\text{night})) =RP(n\text{-}1)+p(n\text{-}1)*RM(n\text{-}1) \quad (25)$$

where P(n-1(night)) is the number of infected individuals on the previous night.

Considering the number of isolated individuals, the rate of change in the number of infected individuals, $\Delta P(n)$, that is, the increment and/or decrement in the number of infected individuals a day in the community, can be calculated by subtracting the number of individuals isolated on day n due to being symptomatic from the number of individuals newly infected on day n. $\Delta P(n)$ is given by the following difference equation:

$$\Delta P(n) = AP(n) - PI(n) = AP(n) - syr(n')*AP(n') \quad (26)$$

where the date n' indicates the day before day n by the 'latent period'. Thus, $PI(n)$ is the number of individuals who were newly infected on day n', were symptomatic on the day after the end of the latent period and were subsequently isolated on day n.

As previously mentioned, $N(n)$ is the current population excluding isolated individuals and dead individuals but including the recovered individuals who returned to the community; that is, $N(n)$ is the total number of individuals currently living and working in the community and is given by the following equation:

$$N(n)=TN(n\text{-}1)-(CI(n\text{-}1)+CPI(n\text{-}1)+CDAS(n\text{-}1)+CDT(n\text{-}1))+CRI(n\text{-}1)+CRT(n\text{-}1) \quad (27)$$

where $TN(n)$ is the total population of the community. For Eq. (27), when n is 1, i.e., the first day of simulation, N (1) is TN (1), which is the initial population of the community, and the other terms are 0. The use of '$(n$-1)' means that the population on the previous night becomes the population on the morning of day n. As previously noted, $TN(n)$ is changed by the number of susceptible individuals ($NAP(n)$) and/or infected individuals ($UP(n)$) who come in and/or leave the community.

$CI(n)$ is the $\Sigma I(n)$, that is, the cumulative number of isolated individuals due to a positive test result; $CPI(n)$ is the $\Sigma PI(n)$, that is, the cumulative number of isolated individuals due to being symptomatic; $CDAS(n)$ is the $\Sigma DAS(n)$, that is, the cumulative number of dead individuals in the infected individuals within the community; $CDT(n)$ is the $\Sigma DT(n)$, that is, the cumulative number of dead individuals in the isolated infected individuals; and $CRI(n)$ is the $\Sigma RI(n)$, that is, the cumulative number of recovered individuals returning from 'isolation due to positive test results', while $CRT(n)$ is the $\Sigma RT(n)$, that is, the cumulative number of recovered individuals returning from 'isolation due to symptom onset'.

For the simulation using Eq. (2) or Eq. (22), when n is 1, i.e., the first day of simulation, N (1) is equal to TN (1), which is the initial population of the community and can be arbitrarily set. RP (1) is equal to P (1), which is the initial number of infected individuals. P (1) can also be set arbitrarily. RM (1) is the initial number of susceptible individuals in the community and is inevitably determined by subtracting P (1) from N (1).

4.3. Change in the number of individuals getting back to susceptible individuals from recovered individuals

As mentioned previously, the effectiveness of the immunity acquired through COVID-19 infection does not continue permanently but decreases gradually and finally falls below a certain threshold, which varies mainly according to the properties/sensitivities of the COVID-19 virus/strain. That is, infection-induced immunity has a duration that indicates the 'validity period of effectiveness of infection-induced immunity'. In the present work, the duration of infection-induced immunity (the validity period of infection-induced immunity) indicates the time interval between when an individual becomes a 'recovered individual' after he/she was once infected with COVID-19 and when his/her immunity acquired through infection decreases below a certain threshold of immunity level at which infection could occur. However, it should be noted that all individuals whose immunity acquired through infection decreases below a certain threshold are not always infected with COVID-19 again. Specifically, individuals whose duration of infection-induced immunity ends substantially get back to 'susceptible individuals' who could be infected, and some of them should become reinfected. The duration of infection-induced immunity is determined by the fact that several weeks and/or several months after individuals recover, infection-induced immunity decreases to below a certain threshold. Although the duration of infection-induced immunity varies from person to person, from a statistical point of view, the average duration (dii) is used in the calculation.

The number of individuals $ReRT(n)$ who got back to susceptible individuals from recovered individuals who were isolated because they were symptomatic is given by the following equation:

$$ReRT(n)=CRT(n\text{-}dii)*bii(n\text{-}dii) \quad (28)$$

where $CRT(n)$ is the $\Sigma RT(n)$ and $RT(n)$ is the number of recovered individuals who were isolated because they were symptomatic in the community. $RT(n)$ is the number of recovered individuals excluding the death toll given by Eq. (20). The variable dii is the duration of infection-induced immunity (the validity period of infection-induced immunity), and the coefficient $bii(n)$ is the 'back-to-rate' at which recovered individuals with infection-induced immunity get back to susceptible individuals a day.

In the calculation, recovered individuals get back to susceptible individuals on day 'dii' days after they return to the community, and on and after the day, they can become infected again. Since the infected individuals recover and return to the community on the 'rp +2' day after infection, the recovered individuals get back to susceptible individuals on the 'rp+2+dii' day after infection. Specifically, for example, when the recovery period (rp) is set to 14 and dii is set to 150, the individuals infected on the first day of simulation recover on day 16 and get back to susceptible individuals on day 166 (=14+2+150), which is the day 150 days after the isolated-recovered individuals return to the community. Conversely, the number of individuals 'getting back to susceptible individuals from isolated-recovered individuals' on day 166, $ReRT$ (166), is given by:

$$ReRT(166)= RT(16)*bii(16)= RT(166 - 150)*bii(166 -150) \quad (29)$$

By replacing 166 with n and 150 with dii, Eq. (29) can be rewritten as Eq. (28).

On the other hand, the number of individuals ($ReRT(n)$) who got back to susceptible individuals from recovered individuals (RT) who were isolated because they were symptomatic decreased with an increasing number of individuals ($APReRT(n)$) who were reinfected among the $ReRT(n)$. Thus,

the cumulative number of susceptible individuals (*JCReRT*(*n*)) who got back from recovered individuals (*RT*) who were isolated due to being symptomatic is given by Eq. (30). *JCReRT*(*n*) is called the 'adjusted *CReRT*(*n*)'.

$$JCReRT(n)= CReRT(n)-CAPReRT(n\text{-}1) \quad (30)$$

where *CReRT*(*n*) is Σ *ReRT*(*n*). *CAPReRT*(*n*)=Σ*APReRT*(*n*), and *APReRT*(*n*) is the number of reinfected individuals among susceptible individuals (*ReRT*) who got back from recovered individuals who were isolated because they were symptomatic. APReRT(n) is given by:

$$APReRT(n)=AP(n)*(JCReRT(n)/RM(n)) \quad (31)$$

Similarly, the number of individuals *ReRI*(*n*) who got back to susceptible individuals from recovered individuals (*RI*) who were isolated because they tested positive is given by:

$$ReRI(n)=CRI(n\text{-}dii)*bii(n\text{-}dii) \quad (32)$$

where *CRI*(*n*)=Σ*RI*(*n*) and *RI*(*n*) is the number of recovered individuals who were isolated because they tested positive and returned to the community after the isolation period ended. *RI*(*n*) is the number of recovered individuals excluding the death toll given by Eq. (18). The 'adjusted *ReRI*(*n*)', that is, *JCReRI*(*n*), is the cumulative number of susceptible individuals who got back from recovered individuals (*RI*) who got back from recovered individuals who were isolated because they tested positive. As in Eq. (30) for *JCReRT*(*n*), *JCReRI*(*n*) is given by:

$$JCReRI(n)= CReRI(n)-CAPReRI(n\text{-}1) \quad (33)$$

where *CReRI*(*n*)=Σ *ReRI*(*n*). *CAPReRI*(*n*)=Σ*APReRI*(*n*), and *APReRI*(*n*) is the number of reinfected individuals among susceptible individuals, *ReRI*(*n*), who got back from recovered individuals who were isolated because they tested positive and is given by:

$$APReRI(n)=AP(n)*(JCReRI(n)/RM(n)) \quad (34)$$

Similarly, the number of individuals (*ReRAS*(*n*)) who got back to susceptible individuals from recovered individuals (*RAS*; asymptomatic-recovered individuals) who were asymptomatic and were not isolated, lived in the community and recovered was as follows:

$$ReRAS(n)=CRAS(n\text{-}dii)*bii(n\text{-}dii) \quad (35)$$

where *CRAS*(*n*) is Σ*RAS*(*n*), and *RAS*(*n*) is the number of recovered individuals who were infected once but did not become symptomatic, were asymptomatic, were not isolated, were living in the community, continued to infect susceptible individuals until the recovery period ended, and subsequently recovered. *RAS*(*n*) is the number of recovered individuals excluding the death toll given by Eq. (17). The 'adjusted *ReRAS*(*n*)' (*JCReRAS*(*n*)), which is the cumulative number of susceptible individuals who got back from asymptomatic-recovered individuals (*ReRAS*):

$$JCReRAS(n)=CReRAS(n)\text{-}CAPReRAS(n\text{-}1) \quad (36)$$

where *CReRAS*(*n*)= Σ*ReRAS*(*n*). *CAPReRAS*(*n*)=Σ*APReRAS*(*n*), and *APReRAS*(*n*) is the number of reinfected individuals among susceptible individuals; *ReRAS*(*n*), who got back from asymptomatic-recovered individuals and is given by:

$$APReRAS(n)=AP(n)*(JCReRAS(n)/RM(n)) \quad (37)$$

Therefore, the total cumulative number of susceptible individuals (*JCReRec*(*n*)) who got back from recovered individuals, excluding the number of individuals who were reinfected (and/or who were infected multiple times), is the 'adjusted total number of susceptible individuals who got back from recovered individuals' and is given by:

$$JCReRec(n)=JCReRI(n)+JCReRT(n)+JCReRAS(n) \quad (38)$$

As explained above, since the number of individuals *ReRI*(*n*) is the number of individuals who got back to susceptible individuals from the recovered individuals (*RI*) who were isolated because they tested positive, *ReRT*(*n*) is the number of individuals who got back to susceptible individuals from the recovered individuals (*RT*) who were isolated because they were symptomatic; the number of individuals, and *ReRAS*(*n*) is the number of individuals who got back to susceptible individuals from the recovered individuals (*RAS*) who were asymptomatic and were not isolated and lived in the community. The total number of susceptible individuals who got back to susceptible individuals from recovered individuals a day (*TReRIRTRAS*(*n*)) is as follows:

$$TReRIRTRAS(n) =ReRI(n)+ ReRT(n)+ReRAS(n) \quad (39)$$

Instead of (*ReRI*(*n*)+ *ReRT*(*n*)+*ReRAS*(*n*)), using *AP* (n), *TReRIRTRAS*(*n*) can be expressed as

$$TReRIRTRAS(n) =AP(n\text{-}((rp+1)+dii)) \quad (40)$$

For example, when the recovery period (*rp*) is set to 14 and dii is set to 200, the individuals who get infected on the first day (on day 1) of simulation would get back to susceptible individuals on day 216 (=1+(14+1)+200), which is the day 200 days after the day when they return to the community after the day the recovery period ends (the first day +(14+1) days), so that would be day (1+(14+1)+ 200). Conversely, the individuals 'getting back to susceptible individuals from recovered individuals on day 216 are the same individuals who got infected on day 1, that is, day '216-((14+1)+200). Thus, *TReRIRTRAS*(216) is given by:

$$TReRIRTRAS\ (216) = AP\ (216\text{-}((14+1)+200))= AP\ (1) \quad (41)$$

By replacing 216 with *n*, 14 with *rp* and 200 with *dii*, Eq. (41) can be rewritten as Eq. (40).

In addition, the sum of the number of recovered individuals in all groups, *TCRITASJ*(*n*), is given by:

$$TCRITASJ(n)=CRIJ(n)+CRTJ(n)+CRASJ(n)- CTAPReRec(n) \quad (42)$$

where *CRIJ*(*n*) is the number of remaining recovered individuals who were isolated because they tested positive:

$$CRIJ(n)=CRI(n)\text{-}JCReRI(n) \quad (43)$$

where, as previously shown, *CRI*(*n*)=Σ*RI*(*n*), and *RI*(*n*) is the number of recovered individuals who were isolated because they

tested positive and returned to the community after the isolation period ended. *RI*(*n*) is the number of recovered individuals excluding the death toll given by Eq. (18). *JCReRI*(*n*), that is, the 'adjusted *ReRI*(*n*)', is, as mentioned earlier, the cumulative number of susceptible individuals who got back from recovered individuals (*RI*) who were isolated because they tested positive and is given by Eq. (33).

CRTJ(*n*) is the number of remaining recovered individuals who were isolated because they were symptomatic:

$$CRTJ(n)=CRT(n)-JCReRT(n) \quad (44)$$

where, as previously shown, *CRT*(*n*) is Σ*RT*(*n*), and *RT*(*n*) is the number of recovered individuals who were isolated because they were symptomatic. *RT*(*n*) is the number of recovered individuals excluding the death toll and is given by Eq. (20). *JCReRT*(*n*) is called the 'adjusted *CReRT*(*n*)' and is given by Eq. (30). *CRASJ*(*n*) is the number of remaining recovered individuals who were asymptomatic, not isolated and remained in the community:

$$CRASJ(n)=CRAS(n)- JCReRAS(n) \quad (45)$$

where, as mentioned previously, *CRAS*(*n*) is Σ*RAS*(*n*), and *RAS*(*n*) is the number of recovered individuals who were infected once but did not become symptomatic, were asymptomatic, were not isolated, were living in the community, continued to infect susceptible individuals until the recovery period ended, and subsequently recovered. *RAS*(n) is the number of recovered individuals excluding the death toll given by Eq. (17). *JCReRAS*(*n*) is the 'adjusted *ReRAS*(*n*)', which is the cumulative number of susceptible individuals who got back from asymptomatic-recovered individuals (*ReRAS*) and is given by Eq. (36).

In Eq. (42), *CTAPReRec*(*n*) indicates the cumulative number of individuals newly reinfected individuals (newly multiple times infected individuals), that is, the cumulative number of individuals who get reinfected among the susceptible individuals who got back from recovered individuals; this number is calculated using Eq. (52) in section **4.5. "Change in the number of reinfected individuals."** Some susceptible individuals who have got back from recovered individuals become infected repeatedly (a second, third, or more multiple infections). *TCRITASJ*(*n*) also indicates the total number of currently existing recovered individuals in the community who have infection-induced immunity just before getting back to susceptible individuals. Thus, the following equation holds:

$$TN(n)=TCRIRTRAS(n)+RM(n)+I2(n)+RP(n) \quad (46)$$

where *TN*(*n*) is the total population of the community, *RM*(*n*) is the number of susceptible individuals, *I*2(*n*) is the number of individuals kept in isolation and *RP*(*n*) is the number of infected individuals in the community ("Spreaders").

4.4. Change in the number of susceptible individuals

The number of susceptible individuals in the community *RM*(*n*) is affected not only by the change in the number of infected individuals (*CI*(*n*)+*CAP*(*n*)) but also by the change in the number of vaccinated individuals (*V*(*n*)) and the number of susceptible individuals (*JCReRec*(*n*)) who got back from recovered individuals and, furthermore, the number of reinfected individuals (*CTAPReRec*(*n*-1)). Thus, the number of susceptible individuals in the community, *RM*(*n*), is given by:

$$RM(n)= TN(n)-(CI(n)+CAP(n)+V(n)) +JCReRec(n)+CTAPReRec(n\text{-}1) \quad (47)\ (=3)$$

where *TN*(*n*) is the total population of the community, *CI*(*n*) is Σ*I*(*n*), *CAP*(*n*) is Σ*AP*(*n*), and *V*(*n*) is given by Eq. (9).

As explained previously by Eq. (38), '*JCReRec* (*n*)' in Eq. (47) is the 'adjusted total number of individuals who get back from recovered individuals', which excludes the number of individuals who were reinfected and returned to the category of 'Infection'. Therefore, since '*JCReRec* (*n*)' represents the number of currently existing susceptible individuals who got back from recovered individuals, *RM*(*n*) decreases as the number of infected individuals (*CAP* (*n*)) increases and increases as *JCReRec* (*n*) increases. *CTAPReRec* (*n*-1) in Eq. (47) is the cumulative number up to the $(n\text{-}1)^{th}$ day of the 'newly reinfected individuals' among the susceptible individuals who got back from recovered individuals. *CAP* (*n*) in Eq. (47) is the cumulative number of infected individuals, including those who have been reinfected, and the same individuals (reinfected individuals) are counted twice (or more). Since these reinfected individuals are subtracted twice (or more), *RM* (*n*) needs to be adjusted by returning the 'same cumulative number of reinfected individuals' up to the previous day, that is, *CTAPReRec* (*n*-1). The calculation of '*CTAPReRec* (*n*)' is explained by Eq. (52) in the following section **4.5. "Change in the number of reinfected individuals."** Eq. (47) suggests that as the number of infected individuals increases with the occurrence of reinfection, the number of susceptible individuals (*JCReRec*) who get back from recovered individuals increases, and since the total number of susceptible individuals (*RM*) also increases, the number of reinfected individuals will inevitably increase, and the duration of infection will also increase.

4.5. Change in the number of reinfected individuals

As previously explained, 'reinfection' refers to not only the second-time infection occurring among susceptible individuals who have got back from recovered individuals with 'first-time infection' but also the infection (third-time infection, fourth, etc.) occurring among susceptible individuals who have got back from recovered individuals with multiple-time infections. The susceptible individuals who got back from recovered individuals could be divided into three categories. For each category, the cumulative number of susceptible individuals is given as follows:

The cumulative number of susceptible individuals (*JCReRI* (*n*)) who got back from recovered individuals (RI), who were isolated because they tested positive, is given by Eq. (33). The cumulative number of susceptible individuals (*JCReRT* (n)) who got back from recovered individuals (*RT*) who were isolated due to being symptomatic is given by Eq. (30), and the cumulative number of susceptible individuals (*JCReRAS* (*n*)) who got back from asymptomatic-recovered individuals (*ReRAS*) is given by Eq. (36). When reinfection occurs, some of these susceptible individuals are reinfected. Therefore, the number of newly reinfected individuals among each of *JCReRI*, *JCReRT*, and *JCReRAS* needs to be calculated multiple times lagged by the duration of infection-induced immunity. The number of newly reinfected individuals (*APReRI* (*n*)) in *JCReRI* (*n*) is given by:

$$APReRI(n)=AP1(n)*(JCReRI(n)/RM(n)) \quad (48)(=34)$$

where $AP1(n)$ is the number of individuals who were newly infected on the nth day, which is equal to $AP(n(\text{night}))$ and is given by Eq. (22). It is noted here that $AP1(n)$ is calculated using $RM(n)$, which is the number of currently existing susceptible individuals, including not only the 'original' susceptible individuals but also the susceptible individuals who got back from recovered individuals who recovered from 'reinfection'. Similarly, the number of newly reinfected individuals ($APReRT$ (n)) for $JCReRT$ (n) is given by:

$$APReRT(n)=AP1(n)*(JCReRT(n)/RM(n)) \quad (49)(=31)$$

Similarly, the number of newly reinfected individuals ($APReRAS$ (n)) for $JCReRAS$ (n) is given by:

$$APReRAS(n)=AP1(n)*(JCReRAS(n)/RM(n)) \quad (50)\ (=37)$$

Thus, the total ($TAPReRec$ (n)) of the number of individuals who were newly reinfected on the nth day among the susceptible individuals who got back from recovered individuals is given by:

$$TAPReRec(n)=APReRI(n)+APReRT(n)+APReRAS(n) \quad (51)$$

The cumulative number of newly reinfected individuals in the susceptible individuals who got back from recovered individuals ($CTAPReRec$ (n)) is given by:

$$CTAPReRec(n) =\Sigma TAPReRec(n) \quad (52)$$

On the other hand, the number of individuals newly infected among the currently existing original susceptible individuals (OS) is given by:

$$APSus(n)=AP1(n)*((RM(n)(CJCReRI(n)+JCReRT(n)+JCReRAS(n)+JCReVacJ(n)))/RM(n)) \quad (53)$$

This $APSus$ (n) represents the number of 'normally infected individuals', that is, the number of 'first-time infected individuals (individuals infected for the first time)', among the remaining original susceptible individuals. The cumulative number ($CAPSus$ (n)) of $APSus$ (n) is given by:

$$CAPSus(n) =\Sigma APSus(n) \quad (54)$$

This infection process in the remaining original susceptible individuals is repeated. Thus, the number of newly infected individuals among the remaining original susceptible individuals also needs to be calculated multiple times lagged by the duration of infection-induced immunity. The total number of individuals infected a day, $AP(n)$ (= $AP1(n)$, which is given by Eq. (2) or Eq. (22)), is the sum of the number of individuals reinfected a day among susceptible individuals who got back from recovered individuals ($TAPReRec$ (n)) and the number of individuals infected a day among the remaining original susceptible individuals ($APSus$ (n)).

5. Results and Discussion

5.1. Changes in the number of infected individuals based on the SIRD model and the flexible compartment model

According to the SIRD model, all infected individuals stay in the community. For the flexible compartment model proposed in this article, when the symptomatic rate, syr, is set to 0, all infected individuals stay in the community. Therefore, when the symptomatic rate was set to 0, the difference in the number of infected individuals was examined between the case when deaths occurred under the SIRD model conditions (where both deceased and recovered individuals are excluded from the community, N remains constant as 'susceptible + infected + recovered + deceased (= initial population)') and the case when deaths occurred under the flexible compartment (FC) model conditions (where deceased individuals are excluded from the community but recovered individuals return to the community, and N changes as 'susceptible + infected within the community - isolated - deceased + recovered individuals who returned to the community').

5.1.1. Change in the number of infected individuals based on the SIRD model

As previously explained, in the SIRD model, infected individuals stay in the community and continue to spread the infection to susceptible individuals until they die. Infected individuals who do not die continue to spread the infection throughout the infection period (recovery period), after which they become recovered individuals.

For the flexible compartment model proposed in this article, when the symptomatic rate, syr, is set to 0, all infected individuals stay in the community. When the sum of the activity levels of the recovered individuals and vaccinated individuals, AL, is set to 0, since the activity of the recovered individuals is 0, the reduction effect on the contact rate between infected individuals and susceptible individuals by recovered individuals becomes 0. When the population in the 'real community' N (n) is set to TN (1), $N(n)$ is the initial population, that is, '$N=S+I+R+D$ (=constant)". Therefore, when the symptomatic rate is set to 0, AL is set to 0, and N (n) is set to TN (1), the flexible compartment model used in this article becomes the same as the SIRD model. Now, consider a case where the community population is 1,000,000 and where the potential (biological) infectious capacity of coronavirus (pfc) is 1.0, the latent period (lp) is 5, the recovery period (rp) is 14, the symptomatic rate (syr) is 0, AL is 0 and N is the total of $S + I + R + D$, that is, TN(1) (=constant).

When the fatality rate (fr) is 0, that is, when any death does not occur, the number of individuals infected a day (AP) increases to a peak of 24,891 on day 80 and then decreases to 0 on day 175. The number of infected individuals (P) increases to a peak of 356,804 on day 87 and then decreases to 0 on day 206, with a total number (TI) of infected individuals of 674,892 (Table 1).

SIRD	Infected/day: *AP*			Infected: *P*			*TI*	*RM*	*CDSUM*	*CDSUM* ratio	Defference from *fr* 0	Increase ratio
pfc 1, *lp* 5, *rp* 14, *syr* 0, AL0, *frI* 0	Date of peak	Number	Date of end	Date of peak	Number	Date of end						
***fr* =0.0**	80	24,891	175	87	356,804	206	674,892	325,108	0	0.000		
***fr* =0.03**	80	24,707	176	88	351,063	207	671,517	328,483	20,146	0.030	-3,375	-0.005
***fr* =0.05**	80	24,574	176	88	347,270	207	669,229	330,771	33,461	0.050	-5,663	-0.008
***fr* =0.1**	80	24,205	177	88	337,674	208	663,369	336,631	66,337	0.100	-11,523	-0.017
***fr* =0.3**	82	22,766	180	89	299,571	210	637,743	362,257	191,323	0.300	-37,149	-0.055
***fr* =0.5**	84	21,194	183	91	262,848	213	607,989	392,011	303,995	0.500	-66,903	-0.099
***fr* =0.7**	87	19,487	186	93	227,028	214	573,028	426,972	401,120	0.700	-101,864	-0.151
***fr* =0.9**	89	17,621	188	95	192,408	215	531,371	468,629	478,284	0.900	-143,521	-0.213
***fr* =1.0**	91	16,633	188	96	175,400	214	507,403	492,597	507,403	1.000	-167,489	-0.248

Table 1: Comparisons of the number of infected individuals among cases with fatality rates of 0.0, 0.03 (3%), 0.05 (5%), 0.1 (10%), 1.0 (100%; all infected individuals died) and others based on the SIRD. For the SIRD model, the *syr* (symptomatic rate) is 0.0 (all infected individuals remain in the community), *AL* (the activity level of the individuals in the community) is 0, which means that even recovered individuals are practically removed from the community, and *N* (= Susceptible (*S*) + Infected (*I*) + Recovered (*R*) + Death (*D*)) is constant at 1,000,000. *AP*: the number of newly infected individuals a day at the peak; *P*: the number of infected individuals at the peak; *TI*: the total number of infected individuals; *RM*: the number of susceptible individuals; and *CDSUM*: the total number of deaths at the end of infection. The potential (biological) infectious capacity of coronavirus *pfc* (*n*) is 1.0, the latent period *lp* (*n*) is 5, and the recovery period *rp* (*n*) is 14. The initial number of infected individuals *P* (1) is 1, and the initial population of the community *TN* (1) is 1,000,000. The "*CDSUM* ratio" indicates the ratio of the total number of deaths (*CDSUM*) to the total number of infected individuals (*TI*), that is, the actual fatality rate. The results calculated using the SIRD model indicate that the total number of infected individuals (*TI*) decreases as the ratio of the number of deaths (*CDSUM* ratio; the fatality rate) increases.

When the fatality rate (*fr*) is 0.1 (10%), that is, when 10% of infected individuals die 10 days after infection (on the 11th day, including the day of infection), the number of individuals infected a day (*AP*) increases to a peak of 24,205 on day 80 and then decreases to 0 on day 177. The number of infected individuals (*P*) increases to a peak of 337,674 on day 88 and then decreases to 0 on day 208, with a total number (*TI*) of infected individuals of 663,369. The number of deceased individuals (*D*) increases to a peak of 2,421 on day 90 and then decreases to 0 on day 169, with a total number of deceased individuals (*CDSUM*) of 66,337.

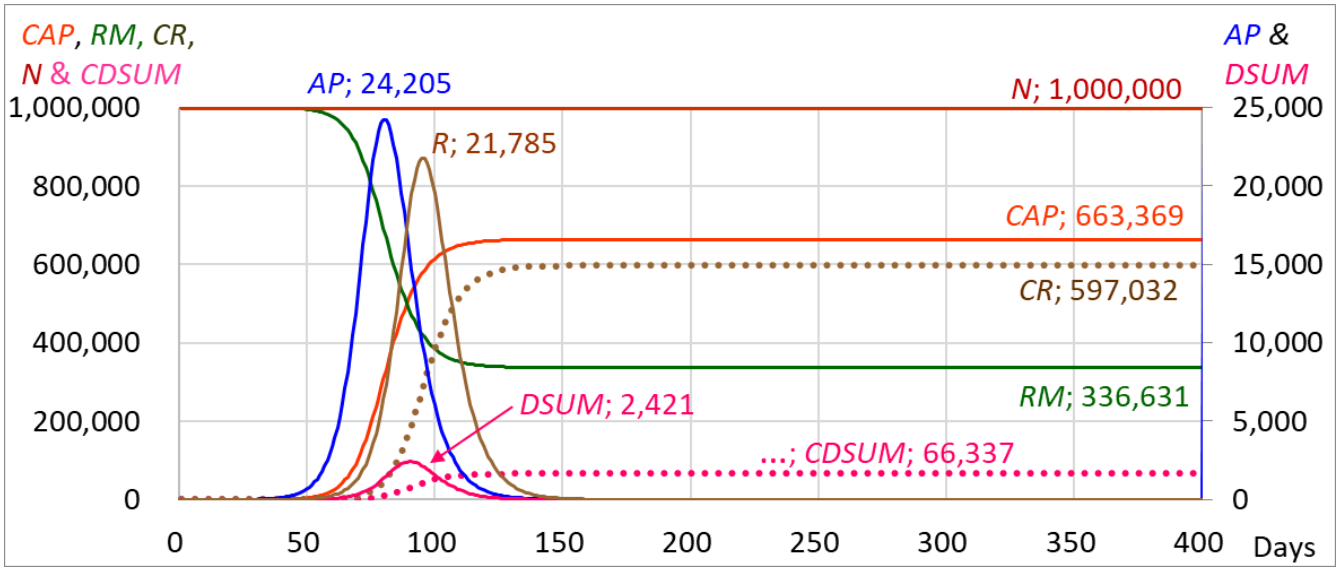

Figure 2: Changes in the number of individuals infected a day (*AP*), the cumulative number of infected individuals (*CAP*), the number of deaths a day (*DSUM*), the cumulative number of deaths (*CDSUM*), the number of susceptible individuals (*RM*), the number of recovered individuals a day within the community (*R*; *RAS*) and the cumulative number of recovered individuals (*CR*) in the SIRD model. **The fatality rate is 0.1.** The community population is 1,000,000, where the potential (biological) infectious capacity of coronavirus (*pfc*) is 1.0, the latent period (*lp*) is 5, the recovery period (*rp*) is 14, the symptomatic rate (*syr*) is 0, *AL* is 0 and the current population of the 'real' community (*N*) is the total population of *S* + *I* + *R* + *D*, that is, *TN*(1) (=1,000,000; constant).

If the fatality rate (*fr*) is 1.0 (100%), that is, when all infected individuals die 10 days after infection, the number of individuals infected a day (*AP*) increases to a peak of 16,633 on day 91 and then decreases to 0 on day 188. The number of infected individuals (*P*) increases to a peak of 175,400 on day 96 and then decreases to 0 on day 214, with a total number (*TI*) of infected individuals of 507,403. The number of deceased individuals (*D*) increased to a peak of 16,633 on day 101 and then to 0 on day 198, with a total number of deceased individuals (*CDSUM*) of 507,403 (Table 1).

As described above, when deaths occur among infected individuals, the SIRD model directly reflects the decrease in the number of "spreaders," inducing a decrease in the number of contacts between infected individuals and susceptible individuals, and the total number of infected individuals (*CAP*) decreases with an increase in the fatality rate (*fr*), that is, with an increase in the ratio of the number of deaths (*CDSUM* ratio; fatality rate) (Table 1, Figure 3).

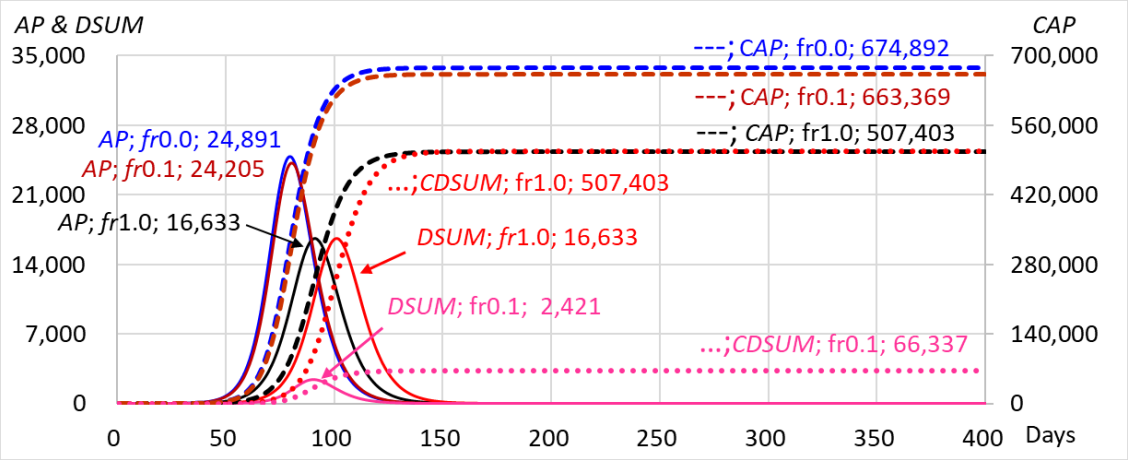

Figure 3: Comparison of *AP* (the number of individuals infected a day), *CAP* (the cumulative number of infected individuals), *DSUM* (the number of deaths a day) and *CDSUM* (the cumulative number of deaths) in cases with fatality rates (*fr*) of 0.0, 0.1 and 1.0. The "AP; *fr*0.0; 24,891" indicates that "the fatality rate (*fr*) is 0.0, and the number of infected individuals a day (*AP*) is 24,891 at the peak". The SIRD model indicates that the total number of infected individuals decreases with an increase in fatality rate, that is, with an increase in the ratio of the number of deaths of infected individuals.

5.1.2. Change in the number of infected individuals based on the modified SIRD model

Under the same conditions as above, that is, setting the symptomatic rate to 0, all infected individuals remain in the community, and setting the activity level (*AL*) of recovered individuals to 0; however, when setting the current population of the community (*N*(*n*)) to the initial population of the community *TN*(1) minus the cumulative number of deaths (*CDSUM*(*n*)); that is, *N*(*n*)=*TN*(1)-*DCDSUM*(*n*), the "flexible compartment model" used in this article can be referred to as the "modified SIRD model".

When the fatality rate (*fr*) is 0, that is, when any death does not occur, the calculation results are the same as those obtained with the SIRD model. Specifically, the number of individuals infected a day (*AP*) increases to a peak of 24,891 on day 80 and then decreases to 0 on day 175. The number of infected individuals (*P*) increases to a peak of 356,804 on day 87 and then decreases to 0 on day 204, with a total number (*TI*) of infected individuals of 674,892 (Tables 1 and 2).

Modified SIRD	Infected/day: *AP*			Infected: *P*			*TI*	*RM*	*CDSUM*	*CDSUM* ratio	Defference from fr 0	Increase ratio
pfc 1, *lp* 5, *rp* 14, *syr* 0, *AL* 0, *frI* 0	Date of peak	Number	Date of end	Date of peak	Number	Date of end						
***fr* =0.0**	80	24,891	175	87	356,804	206	674,892	325,108	0	0.000		
***fr* =0.03**	80	24,875	176	88	353,635	207	677,503	322,497	20,325	0.030	2,611	0.004
***fr* =0.05**	80	24,851	177	88	351,511	208	679,297	320,703	33,965	0.050	4,405	0.007
***fr* =0.1**	81	24,763	179	88	345,921	209	683,987	316,013	68,399	0.100	9,095	0.013
***fr* =0.3**	83	24,519	186	90	324,234	217	706,395	293,605	211,919	0.300	31,503	0.047
***fr* =0.5**	85	24,238	197	92	303,031	229	737,790	262,210	368,895	0.500	62,898	0.093
***fr* =0.7**	89	23,996	216	95	282,555	250	787,310	212,690	551,117	0.700	112,418	0.167
***fr* =0.9**	93	23,795	262	98	262,973	304	887,244	112,756	798,520	0.900	212,352	0.315
***fr* =1.0**	95	23,756	324	100	253,656	386	1,000,000	0	1,000,000	1.000	325,108	0.482

Table 2: Comparisons of the number of infected individuals among cases with fatality rates of 0.0, 0.03 (3%), 0.05 (5%), 0.1 (10%), 1.0 (100%; all infected individuals died) and others based on the modified SIRD. For the modified SIRD model, the *syr* (symptomatic rate) is 0.0 (all infected individuals remain in the community), *AL* (the activity level of the recovered individuals in the community) is 0, which means that even recovered individuals are practically removed from the community, and the current population of the community (*N*(*n*)) is the population excluding the cumulative number of deaths; *N*(*n*)=*TN*(1)-*CDSUM*(*n*). *AP*: the number of newly infected individuals a day at the peak; *P*: the number of infected individuals at the peak; *TI*: the total number of infected individuals; *RM*: the number of susceptible individuals; and *CDSUM*: the total number of deaths at the end of infection. The potential (biological) infectious capacity of coronavirus *pfc* (*n*) is 1.0, the latent period *lp* (*n*) is 5, and the recovery period *rp* (*n*) is 14. The initial number of infected individuals *P* (1) is 1, and the initial population of the community *TN* (1) is 1,000,000. The "*CDSUM* ratio" indicates the ratio of the total number of deaths (*CDSUM*) to the total number of infected individuals (*TI*), that is, the actual fatality rate. The results calculated using the modified SIRD model indicate that the total number of infected individuals (*TI*) increases as the ratio of the number of deaths (*CDSUM* ratio; the fatality rate) increases.

When the fatality rate (*fr*) is 0.1 (10%), that is, when 10% of infected individuals die 10 days after infection (on the 11th day, including the day of infection), the number of deaths (*D*) increases to a peak of 2,476 on day 91 and then decreases to 0 on day 170, and the total number of deaths, *CDSUM*, reaches 68,399 on day 194. On the other hand, *N* decreases from 1,000,000 to 931,601 on day 194; that is, *N* (194) = 931,601. The number of recovered individuals a day (*R*) increases to a peak of 22,287 on day 96 and then decreases to 0 on day 193, and the total number of recovered individuals (*CR*) reaches 615,588 on day 205 (Figure 4).

The number of individuals infected a day (*AP*) increases to a peak of 24,763 on day 81 and then decreases to 0 on day 179. The number of infected individuals (P) increases to a peak of 345,921 on day 88 and then decreases to 0 on day 209, with a total number (*TI*) of infected individuals (*TI*) of 683,987 (Table 2, Figure 4).

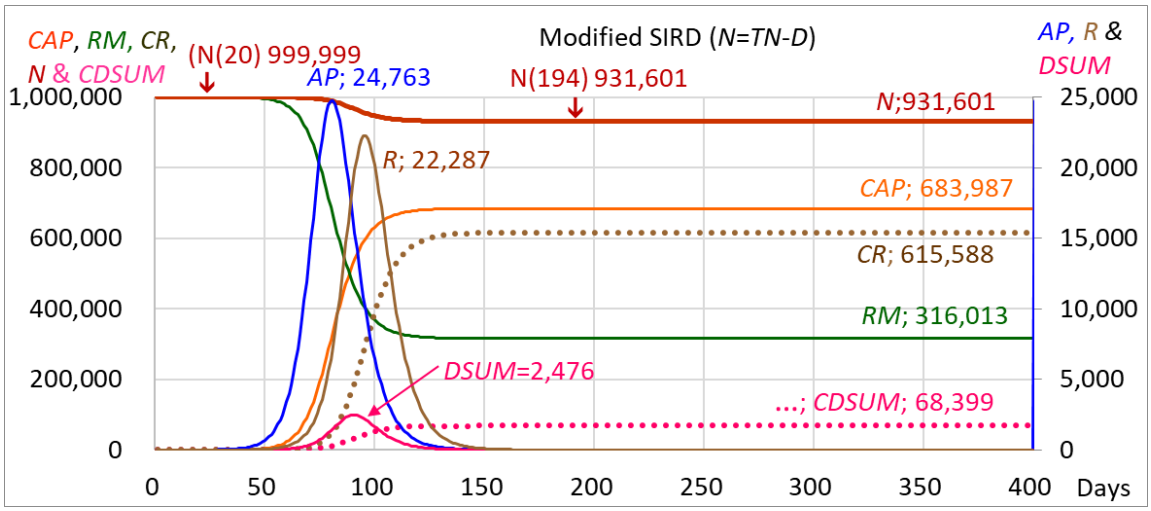

Figure 4: Changes in the current population of the 'real' community (*N*), the number of individuals infected a day (*AP*), the cumulative number of infected individuals (*CAP*), the number of deaths a day (*DSUM*), the cumulative number of deaths (*CDSUM*), the number of susceptible individuals (*RM*), the number of recovered individuals a day within the community (*R*; *RAS*) and the cumulative number of recovered individuals (*CR*) in the modified SIRD model. **The fatality rate is 0.1.** The community population is 1,000,000, where the potential (biological) infectious capacity of coronavirus (*pfc*) is 1.0, the latent period (*lp*) is 5, the recovery period (*rp*) is 14, the symptomatic rate (*syr*) is 0, *AL* is 0 and *N* is the total of *S* + *I* + *R* - *D*, that is, *N*(*n*)=*TN*(1) -*CDSUM* (*n*).

If the fatality rate (*fr*) is 1.0 (100%), that is, when all infected individuals die on the 10th day after infection, the number of individuals infected a day (*AP*) increases to a peak of 23,756 on day 95 and then decreases to 0 on day 324. The number of infected individuals (*P*) increases to a peak of 253,656 on day 100 and then decreases to 0 on day 386. The total number of infected individuals reaches 1,000,000. The number of deceased individuals (*D*) increases to a peak of 23,756 on day 105 and then decreases to 0 on day 334. The total number of deaths, *CDSUM*, reaches 1,000,000 on day 396, meaning that the community will disappear (Table 2).

As shown above, when deaths occur among the infected individuals, according to the modified SIRD model, the number of spreaders decreases, but since the population of the community decreases, both the contact rate and the infection coefficient (the infectious capacity) increase (see Eq. (1) and Eq. (23)), and the total number of infected individuals (*CAP*) increases with the increase in the fatality rate (*fr*), that is, with the increase in the ratio of the number of deaths (*DSUM* ratio; fatality rate; *fr*) (Table 2, Figure 5). It is indicated that it is important to incorporate into calculations the fact that the population of the community decreases when deaths occur among infected individuals.

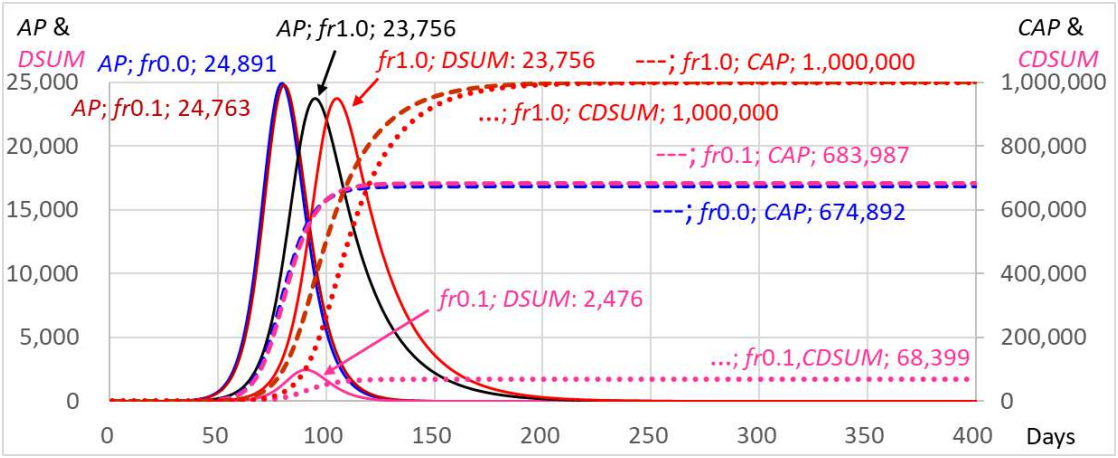

Figure 5: Comparison of *AP* (the number of individuals infected a day), *CAP* (the cumulative number of infected individuals), *DSUM* (the number of deaths a day) and *CDSUM* (the cumulative number of deaths) in cases with fatality rates (*fr*) of 0.0, 0.1 and 1.0. The modified SIRD model indicates that the total number of infected individuals increases with an increase in fatality rate, that is, with an increase in the ratio of the number of deaths of infected individuals.

5.1.3. Change in the number of infected individuals based on the flexible compartment model

According to the flexible compartment model, deceased individuals are excluded from the community, but recovered individuals return to the community. Therefore, the current population of the community ($N(n)$) is the initial population of the community minus the number of currently isolated individuals and the number of deaths but plus the number of recovered individuals and is given by Eq. (27), that is,

$$N(n)=TN(n\text{-}1) -(CI(n\text{-}1) +CPI(n\text{-}1) +CDAS(n\text{-}1) +CDT(n\text{-}1)) +CRI(n\text{-}1) +CRT(n\text{-}1) \quad (27)$$

where $TN(n)$ is the total population of the community. When n is 1, i.e., the first day of simulation, N (1) is TN (1). $CI(n)$ is the cumulative number of isolated individuals due to a positive test, and $CPI(n)$ is the cumulative number of isolated individuals due to being symptomatic. $DAS(n)$ is the cumulative number of dead individuals among the infected individuals within the community, and $CDT(n)$ is the cumulative number of dead individuals among the isolated infected individuals. Thus, ($CDAS(n)$+$CDT(n)$) is the cumulative number of deaths (the cumulative number of dead individuals), that is, $CDSUM$ (n). ($CRI(n)$+$CRT(n)$) indicates the total cumulative number of the cumulative number ($CRI(n)$) of recovered individuals who returned from 'isolation due to positive results in the test' and the cumulative number ($CRT(n)$) of recovered individuals who returned from 'isolation due to symptom onset'. Using the cumulative number of deaths ($CDSUM(n)$), Eq. (27) can be rewritten as Eq. (27'):

$$N(n)=TN(n\text{-}1) -(CI(n\text{-}1) +CPI(n\text{-}1) +CDSUM(n\text{-}1)) +CRI(n\text{-}1) +CRT(n\text{-}1) \quad (27')$$

When the symptomatic rate is set to 0, all infected individuals remain within the community, and recovered individuals who have acquired immunity also stay in the community. The isolated individuals and the recovered individuals returning from isolation do not occur. The current population of the community ($N(n)$) is inevitably the total population (the initial population in this case) of the community minus the cumulative number of deaths ($CDSUM(n)$); that is, $N(n) = TN(n) – CDSUM(n)$. As a matter of course, in calculations, since recovered individuals ($RAS(n)$: R in Figure 6) live in the community, they are included in the current population $N(n)$. When the activity level of recovered individuals (AL) is set to 1, since the activity level of recovered individuals is the same as that of susceptible individuals, it is possible to more accurately represent the behavior of COVID-19-infected and recovered individuals and the infection status in the community. The flexible compartment model used in this article, which appropriately represents this situation, yields result different from those of the SIRD model and the modified SIRD model as follows:

When the fatality rate (fr) is 0, that is, when no deaths occur, the calculation results are not the same as those obtained with the SIRD model or the modified SIRD model. Specifically, in the flexible compartment mode (FC), the number of individuals infected a day (AP) increased to a peak of 23,655 on day 79 and then decreased to 0 on day 153. The number of infected individuals (P) increased to a peak of 336,268 on day 87 and then decreased to 0 on day 178, with a total number (TI) of infected individuals of 598,287 (Table 3). The total number of infected individuals, 598,287, was 76,605 fewer than the 674,892 individuals predicted by the SIRD model.

Citation : Ohmori H (2026) Effect of Death on the Spread of COVID-19 Evaluated by a Flexible Compartment Model. Ameri J Clin Med Re : AJCMR-254. https://doi.org/10.71010/2835-9496/ajcmr-e254.

FC	Infected/day: *AP*			Infected: *P*			*TI*	*RM*	*CDSUM*	*CDSUM* ratio	Defference from fr 0	Increase ratio
pfc 1, *lp* 5, *rp* 14, *syr* 0, *AL* 1; *frI* 0	Date of peak	Number	Date of end	Date of peak	Number	Date of end						
***fr* =0.0**	79	23,655	153	87	336,268	178	598,287	401,713	0	0.000		
***fr* =0.01**	79	23,641	153	87	335,345	178	599,205	400,795	5,992	0.010	918	0.002
***fr* =0.02**	79	23,631	153	87	334,407	179	600,135	399,865	12,003	0.020	1,848	0.003
***fr* =0.03**	79	23,615	154	87	333,454	179	601,077	398,923	18,032	0.030	2,790	0.005
***fr* =0.05**	80	23,594	154	87	331,498	179	602,999	397,001	30,150	0.050	4,712	0.008
***fr* =0.1**	80	23,584	156	88	326,593	181	608,035	391,965	60,804	0.100	9,748	0.016
***fr* =0.3**	82	23,448	163	89	308,124	188	632,337	367,663	189,709	0.300	34,050	0.057
***fr* =0.5**	85	23,384	173	92	290,677	199	666,906	333,094	333,453	0.500	68,619	0.115
***fr* =0.7**	88	23,379	189	94	274,270	217	722,476	277,524	505,733	0.700	124,189	0.208
***fr* =0.9**	92	23,542	234	98	259,867	269	840,886	159,114	756,798	0.900	242,599	0.405
***fr* =1.0**	95	23,756	324	100	253,655	386	1,000,000	0	1,000,000	1.000	401,713	0.671

Table 3: Comparisons of the number of infected individuals among cases with fatality rates of 0.0, 0.03 (3%), 0.05 (5%), 0.1 (10%), 1.0 (100%; all infected individuals died) and others based on the flexible compartment model. The *syr* (symptomatic rate) is 0.0 (all infected individuals remain in the community), the *AL* (the activity level of the recovered individuals who are staying the community) is 1, which means that the activity of recovered individuals is equal to that of the susceptible individuals, and the current population of the community (*N*(*n*)) is the population excluding the number of deaths, that is, *N*(*n*) = *TN*(*n*) –*CDSUM*(*n*). *AP*: the number of newly infected individuals a day at the peak; *P*: the number of infected individuals at the peak; *TI*: the total number of infected individuals; *RM*: the number of susceptible individuals; and *CDSUM*: the total number of deaths at the end of infection. The potential (biological) infectious capacity of coronavirus *pfc* (*n*) is 1.0, the latent period *lp* (*n*) is 5, and the recovery period *rp* (*n*) is 14. The initial number of infected individuals *P* (1) is 1, and the initial population of the community *TN* (1) is 1,000,000. The "*CDSUM* ratio" indicates the ratio of the total number of deaths (*CDSUM*) to the total number of infected individuals (*TI*), that is, the actual fatality rate. The results calculated using the flexible compartment model indicate that the total number of infected individuals (*TI*) increases as the ratio of the number of deaths (*CDSUM* ratio; the fatality rate) increases.

When the fatality rate (*fr*) is 0.1 (10%), that is, when 10% of infected individuals die 10 days after infection (on the 11th day, including the day of infection), the number of deaths (*D*) increases to a peak of 2,358 on day 90 and then decreases to 0 on day 152, and the total number of deaths, CDSUM, reaches 60,804 on day 178. On the other hand, *N* decreases from 1,000,000 to 939,196 on day 178; that is, *N* (178) = 939,196. The number of recovered individuals a day (*R*) increases to a peak of 21,226 on day 95 and then decreases to 0 on day 170, and the cumulative number of recovered individuals (*CR*) reaches 547,231 on day 183 (Figure 6).

The number of individuals infected a day (*AP*) increases to a peak of 23,584 on day 80 and then decreases to 0 on day 156. The number of infected individuals (*P*) increases to a peak of 326,593 on day 88 and then decreases to 0 on day 181 with a total number of infected individuals of 608,035 (Table 3, Figure 6).

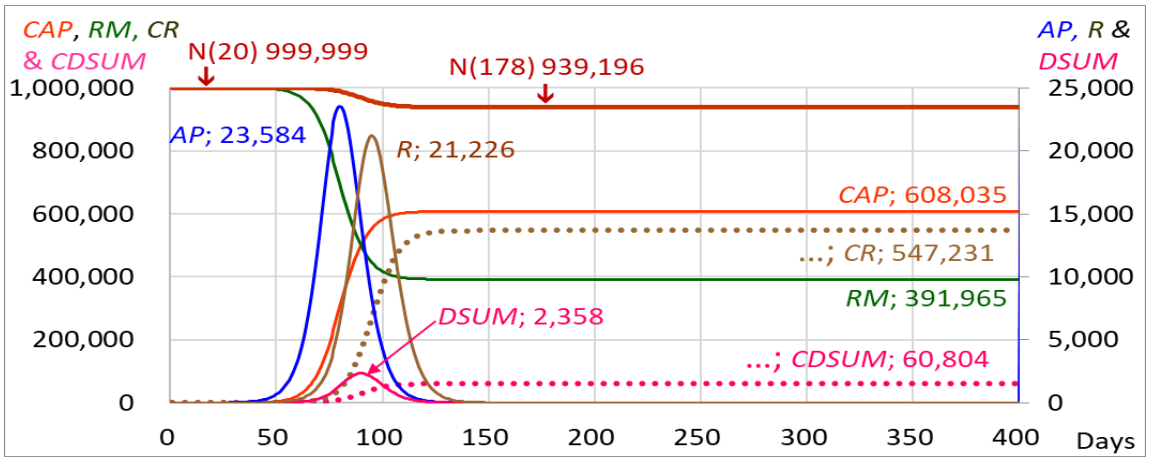

Figure 6: Changes in the current population of the 'real' community (*N*), the number of individuals infected a day (*AP*), the cumulative number of infected individuals (*CAP*), the number of deaths a day (*DSUM*), the cumulative number of deaths (*CDSUM*), the number of susceptible individuals (*RM*), the number of recovered individuals a day within the community (*R*; *RAS*) and the cumulative number of recovered individuals (*CR*) in the flexible compartment model. **The fatality rate is 0.1.** The community population is 1,000,000, where the potential (biological) infectious capacity of coronavirus (*pfc*) is 1.0, the latent period (*lp*) is 5, the recovery period (*rp*) is 14, the symptomatic rate (*syr*) is 0, *AL* is 1 and *N* is the current population excluding the number of deaths, that is, *N*(*n*) = *TN*(*n*) –*CDSUM*(*n*).

If the fatality rate (*fr*) is 1.0 (100%), that is, when all infected individuals die on the 10th day after infection, since there are no recovered individuals, the calculation results are the same as those from the modified SIRD model. Specifically, the number of individuals infected a day (*AP*) increases to a peak of 23,756 on day 95 and then decreases to 0 on day 324. The number of infected individuals (*P*) increases to a peak of 253,656 on day 100 and then decreases to 0 on day 386. The total number of infected individuals reaches 1,000,000. The number of deceased individuals (*D*) increases to a peak of 23,756 on day 105 and then decreases to 0 on day 396. The total number of deaths, *CDSUM*, reaches 1,000,000 on day 396, meaning that the community will disappear (Tables 2 and 3).

As examined above, when deaths occur among infected individuals, in the flexible compartment model, since the number of recovered individuals (*R*) decreases, the 'contact rate reduction effect by recovered individuals' decreases, and the contact rate increases (see Eq. (1)). As a result, the total number of infected individuals (*CAP*) increases with an increase in the fatality rate (*fr*), that is, with an increase in the ratio of the number of deaths among the infected individuals (*DSUM* ratio) (Table 3, Figure 7). Furthermore, when deaths occur, the population of the 'real community' (*N* (*n*)) decreases, increasing the contact rate (see Eq. (1)) and increasing also the infection coefficient (the infectious capacity) (see Eq. (23)), the increase in the total number of infected individuals is intensified.

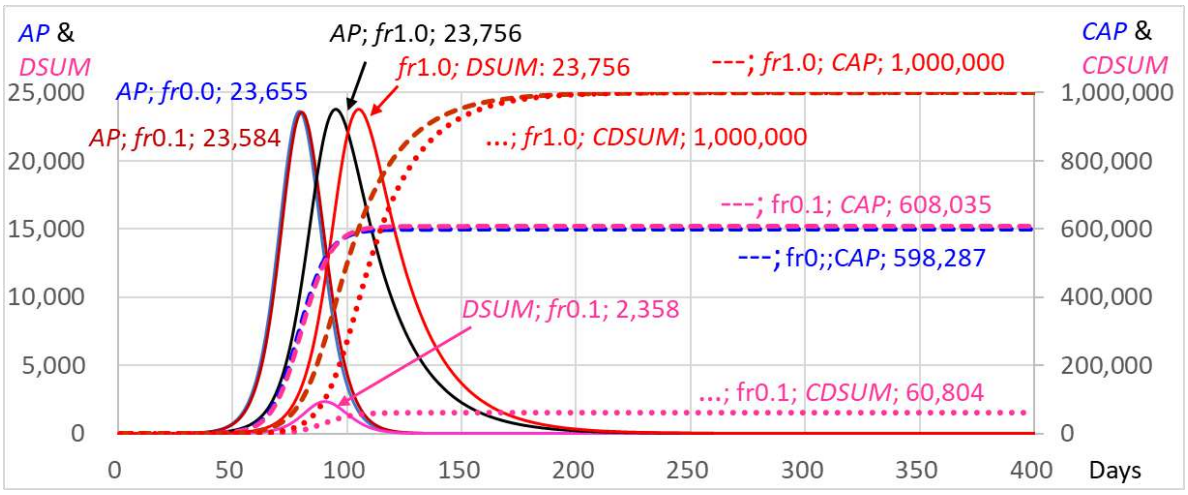

Figure 7: Comparison of *AP* (the number of individuals infected a day), *CAP* (the cumulative number of infected individuals), *DSUM* (the number of deaths a day) and *CDSUM* (the cumulative number of deaths) in cases with fatality rates (*fr*) of 0.0, 0.1 and 1.0. The flexible compartment model indicates that the total number of infected individuals increases with an increase in the fatality rate, that is, with an increase in the ratio of the number of deaths of infected individuals.

As shown in Table 1, according to the SIRD model, the total number of infected individuals decreased with increasing fatality rate, with a total number of infected individuals of 674,892 at a fatality rate of 0.0; moreover, 663,369 at a fatality rate of 0.1 and 507,403 at a fatality rate of 1.0, respectively (Figure 8).

According to the modified SIRD model, the total number of infected individuals increases with increasing fatality rate, with a total number of infected individuals of 674,892 at a fatality rate of 0.0, 683,987 at a fatality rate of 0.1 and 1,000,000 at a fatality rate of 1.0, respectively (Figure 8). If the fatality rate is 1.0, everyone in the community will die.

According to the flexible compartment model, 598,287 individuals were infected at a fatality rate of 0.0. As previously noted, the total number of infected individuals of 598,287 is 76,605 fewer than the 674,892 predicted by the SIRD model. This is the result of recovered individuals returning to the community and reducing the contact rate between infected and susceptible individuals, that is, the 'contact rate reduction effect by recovered individuals'. However, the total number of infected individuals increased with an increase in the fatality rate as the total number of infected individuals increased to 602,999 at a fatality rate of 0.05, 608,035 at a fatality rate of 0.1, 666,906 at a fatality rate of 0.5 and 1,000,000 at a fatality rate of 1.0 (Table 3 and Figure 8).

This is because, in a flexible compartment model, the number of deaths, the number of recovered individuals, and the population of the 'real community' are appropriately taken into account in the calculations. Specifically, when the symptomatic rate is set to 0, that is, when no deaths occur among the infected individuals, the number of recovered individuals does not decrease and reaches its maximum, so the "contact reduction effect by recovered individuals" also reaches its maximum, minimizing the contact rate between infected and susceptible individuals (see Eq. (1)); as a result, the total number of infected individuals reaches its minimum. However, when deaths occur, since the number of recovered individuals (*R*) decreases, reducing the 'contact rate reduction effect by recovered individuals' and increasing the number of contacts between infected and susceptible individuals (see Eq. (1)), the total number of infected individuals increases (Figure 9).

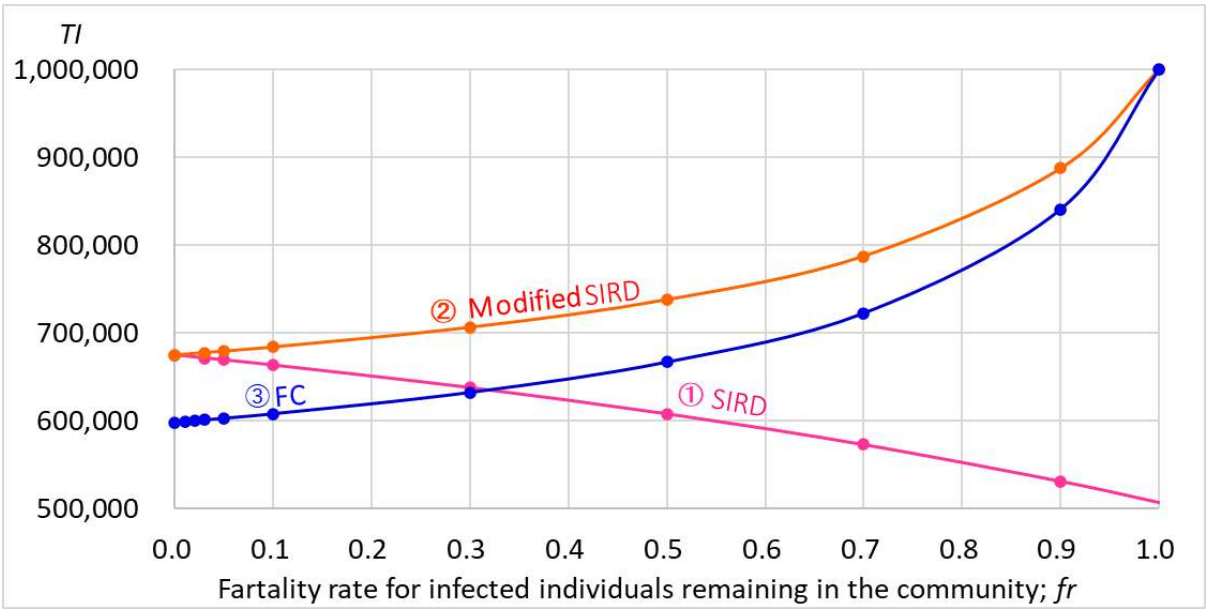

Figure 8: Comparison of the total number of infected individuals *(TI)* between models according to differences in fatality rates.

① According to the SIRD model, infected individuals stay in the community and continue to spread the infection to susceptible individuals until they die. Infected individuals who do not die continue to spread the infection throughout the infection period (recovery period), after which they become recovered individuals. The current population of the community ($N(n)$) is kept as the initial population of the community, that is, $N=TN=S+I+R+D$.

② In the "Modified SIRD model", the condition of infected individuals is the same as that in the SIRD model, but the value of $N(n)$ is equal to the initial population of the community minus the number of deaths; that is, $N(n)=TN(1)-D(n)$ $(=TN(1)-CDSUM(n))$.

③ In the flexible compartment model (FC), the condition of the infected individuals is the same as that in the SIRD model, but the current population of the community ($N(n)$) is the total population minus the cumulative number of deaths; that is, $N(n) = TN(n) - CDSUM(n)$.

As previously noted, when deaths occur among infected individuals, the number of "spreaders" decreases; however, in a flexible compartment model, the number of recovered individuals (*RM*) also decreases, reducing the "contact rate reduction effect by recovered individuals," which increases the contact rate between infected individuals and susceptible individuals (see Eq. (1)), resulting in an increase in the total number of infected individuals (Figure 9). Furthermore, when deaths occur, since the population of the 'real community' (*N*) decreases, increasing the contact rate (see Eq. (1)) and increasing the infection coefficient (the infectious capacity) (see Eq. (23), Figure 10), the increase in the total number of infected individuals is intensified.

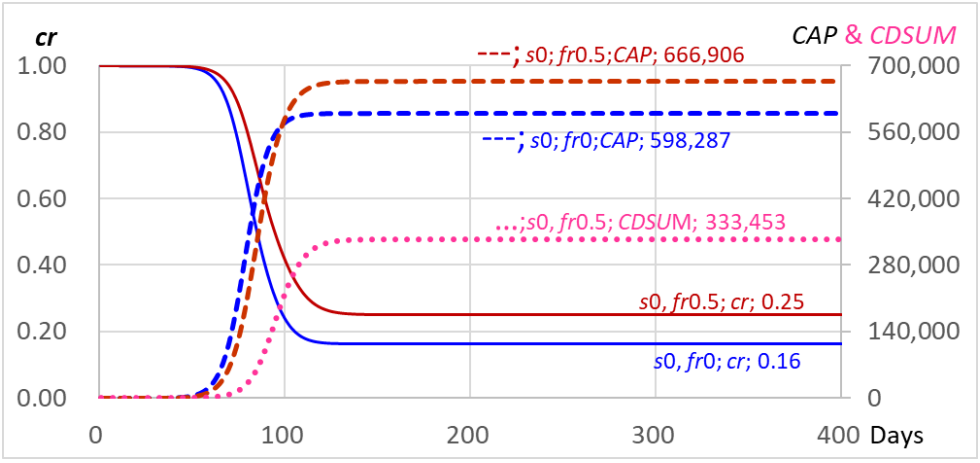

Figure 9: Changes in the contact rate (*cr*), the cumulative number of infected individuals (*CAP*) and the cumulative number of deaths (*CDSUM*) in the flexible compartment model (FC model), showing the difference when the fatality rate (*fr*) is 0 or 0.5. When deaths occur among infected individuals (*fr*0.5), the contact rate increases compared to when there are no deaths (*fr*0), and the total number of infected individuals increases. The symptomatic rate (*s*) is 0.0, indicating that all infected individuals remain in the community.

The changes in the infection coefficient (*p*: the infectious capacity), the number of infected individuals a day (*AP*) and the number of deaths a day (*DSUM*) are shown in Figure 10.

As previously noted, the infectious capacity (*p*) is greater when deaths occur (*fr*0.5) than when there are no deaths (*fr*0).

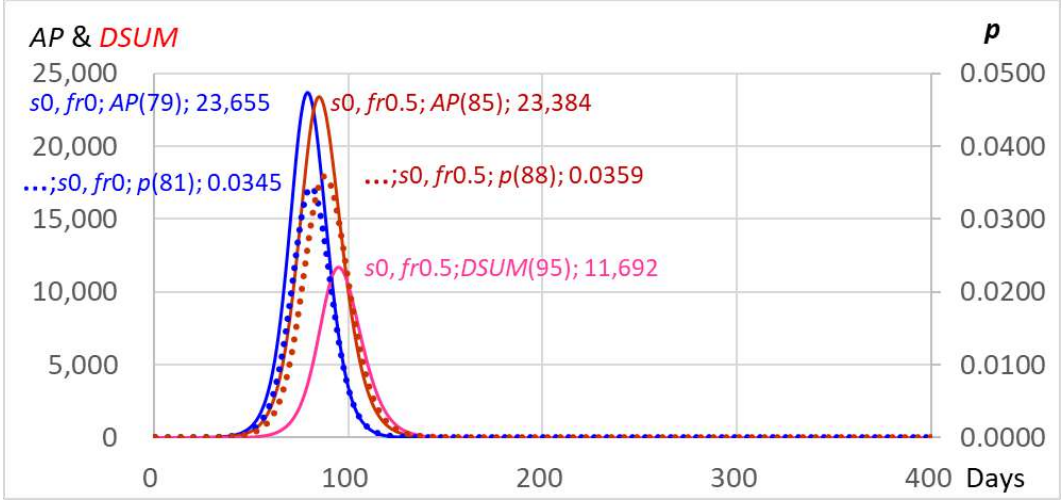

Figure 10: Changes in the infection coefficient (*p*; the infectious capacity), the number of infected individuals a day (*AP*) and the number of deaths a day *(DSUM*) in the flexible compartment model (FC model) are shown, with differences occurring when the fatality rate is 0 or 0.5. The symptomatic rate is 0, where all infected individuals remain in the community. The "*s*0, *fr*0; *AP* (79); 23,655" indicates that "the symptomatic rate (*s*) is 0, the fatality rate (*fr*) is 0, and the number of infected individuals a day (*AP*) is 23,655 at the peak on day 79".

The SIRD model and the modified SIRD models tend to overestimate the number of infected individuals because they do not appropriately reflect the number of deaths and recovered individuals in the calculations. Furthermore, in the SIRD models, when deaths occur among infected individuals, they provide misleading information about a decrease in the total number of infected individuals, leading to misunderstandings about the dynamics of COVID-19 infection. Therefore, caution is necessary when using these models.

5.2. Changes in the total number of infected individuals due to differences in case fatality rates for different symptomatic rates based on the flexible compartment model

In the previous chapter, the differences between models in terms of the number of infected individuals were examined when death occurred when the symptom rate was set to 0, that is, when all infected individuals remained in the community. However, in the case of COVID-19, infected individuals are isolated once they develop symptoms. In the flexible compartment model, the symptomatic rate essentially corresponds to the isolation rate. Therefore, for cases with several different symptomatic rates, changes in the total number of infected individuals due to differences in the fatality rate were examined. In this chapter, the coefficient '*AL* (activity level of recovered individuals in the community)' of the flexible compartment model is set to 1; that is, 'the activity of recovered individuals is equivalent to the activity of susceptible individuals.

5.2.1. Change in the total number of infected individuals due to differences in case fatality rates for the symptomatic rate of 1.0

When the symptom rate is set to 1.0, all infected individuals develop symptoms on the day after the end of the latent period and are isolated the next day; they become recovered individuals, excluding the deceased, on the day after the end of the recovery period (isolation period) and return to the community the next day. The current population of the community (*N*(*n*)) is the total population (initial population in this case) of the community minus the number of isolated individuals and the number of deaths, plus the number of recovered individuals, that is, as explained previously, given by Eq. (27'): $N(n)=TN(n\text{-}1)-(CI(n\text{-}1)+CPI(n\text{-}1)+CDSUM(n\text{-}1))+CRI(n\text{-}1)+CRT(n\text{-}1)$. *TN*(*n*) is the total population of the community. When *n* is 1, i.e., the first day of simulation, *N* (1) is *TN* (1). *CI*(*n*) is the cumulative number of isolated individuals due to testing positive, *CPI*(*n*) is the cumulative number of isolated individuals due to being symptomatic, and *CDSUM* (*n*) is the cumulative number of deaths. (*CRI*(*n*)+*CRT*(*n*)) indicates the total cumulative number of the cumulative number (*CRI*(*n*)) of recovered individuals who returned from 'isolation due to positive results in the test' and the cumulative number (*CRT*(*n*)) of recovered individuals who returned from 'isolation due to symptom onset'.

When the fatality rate (*frI*) is 0, that is, when no deaths occur among isolated infected individuals, the number of individuals infected a day (*AP*) increases to a peak of 2,135 on days 191 and 192 and then decreases to 0 on day 326. The number of infected individuals (*P*) increases to a peak of 14,895 on day 194 and then decreases to 0 on day 354, with a total number (*TI*) of infected individuals of 141,787 (Table 4). This total number, 141,787, of infected individuals is significantly fewer by 456,500 compared to 598,287 individuals when the symptomatic rate was set to 0.0, indicating that the symptomatic rate had a large effect on the occurrence of infection (Tables 4 and 3).

FC	Infected/day: *AP*			Infected: *P*			*TI*	*RM*	*CDSUM*	*CDSUM* ratio	Defference from *fr* 0	Increase ratio
pfc 1, *lp* 5, *rp* 14, *syr* 1, *AL* 1, *fr* 0	Date of peak	Number	Date of end	Date of peak	Number	Date of end						
***frI* 0.0**	191-192	2,135	326	194	14,895	354	141,787	858,213	0	0.000		
***frI* 0.03**	192	2,185	327	195	15,243	355	145,289	854,711	4,359	0.030	3,502	0.025
***frI* 0.05**	192	2,220	328	195	15,485	356	147,722	852,278	7,386	0.050	5,935	0.042
***frI* 0.1**	193	2,311	330	196	16,122	358	154,181	845,819	15,418	0.100	12,394	0.087
***frI* 0.3**	197	2,767	339	200	19,302	369	186,978	813,022	56,093	0.300	45,191	0.319
***frI* 0.5**	201	3,449	353	204	24,067	395	237,983	762,017	118,992	0.500	96,196	0.678
***frI* 0.7**	208	4,587	377	211	32,010	411	329,411	670,589	230,590	0.700	187,624	1.323
***frI* 0.9**	218	6,903	445	221	48,209	488	556,494	443,506	500,845	0.900	414,707	2.925
***frI* 1.0**	227	9,387	706	230	65,599	884	1,000,000	0	1,000,000	1.000	858,213	6.053

Table 4: Comparisons of the number of infected individuals among cases with fatality rates of 0.0, 0.03 (3%), 0.05 (5%), 0.1 (10%), 1.0 (100%; all infected individuals died) and others. The calculations were carried out using the flexible compartment model. The *syr* (symptomatic rate is 10 (all infected individuals are isolated from the community), *AL* (the activity level of the recovered individuals who are in the community) is 1, which indicates that the activity of the recovered individuals is equal to that of the susceptible individuals. In addition, N is the current population excluding both the number of isolated individuals and the number of deaths but including the number of recovered individuals, that is, $N(n)=TN(n\text{-}1)-(CI(n\text{-}1)+CPI(n\text{-}1)+CDSUM(n\text{-}1))+CRI(n\text{-}1)+CRT(n\text{-}1)$. *AP*: the number of newly infected individuals a day at the peak; *P*: the number of infected individuals at the peak; *TI*: the total number of infected individuals; *RM*: the number of susceptible individuals; and *CDSUM*: the total number of deaths at the end of infection. The potential (biological) infectious capacity of coronavirus *pfc* (*n*) is 1.0, the latent period *lp* (*n*) is 5, and the recovery period *rp* (*n*) is 14. The initial number of infected individuals *P* (1) is 1, and the initial population of the community *TN* (1) is 1,000,000. The "*CDSUM* ratio" indicates the ratio of the total number of deaths (*CDSUM*) to the total number of infected individuals (*TI*), that is, the actual fatality rate. The results calculated using the flexible compartment model indicate that the total number of infected individuals (*TI*) increases as the ratio of the number of deaths (*CDSUM* ratio; the fatality rate) increases.

When the fatality rate of isolated individuals (*frI*) is 0.1 (10%), that is, when 10% of isolated-infected individuals die 10 days after infection (on the 11th day, including the day of infection), that is, 4 days after isolation (on the 5th day, including the day of isolation), the number of deaths (*D*) increases to a peak of 231 from day 202 to day 204 and then decreases to 0 on day 309, and the total number of deaths, *CDSUM*, reaches 15,418 on day 338. On the other hand, *N* decreases from 1,000,000 to 971,314 on day 209, that is, *N* (209) = 971,314, and then increases to 984,582 on day 984,582. The number of recovered individuals a day (*R*) increases to a peak of 2,080 on day 208 and then decreases to 0 on day 343, and the total number of recovered individuals (*CR*) reaches 138,764 on day 382 (Figure 11).

The number of individuals infected a day (*AP*) increases to a peak of 2,311 on day 193 and then decreases to 0 on day 330. The number of infected individuals (*P*) increases to a peak of 16,122 on day 196 and then decreases to 0 on day 358. The total number of infected individuals reaches 154,181 (Table 4, Figure 11).

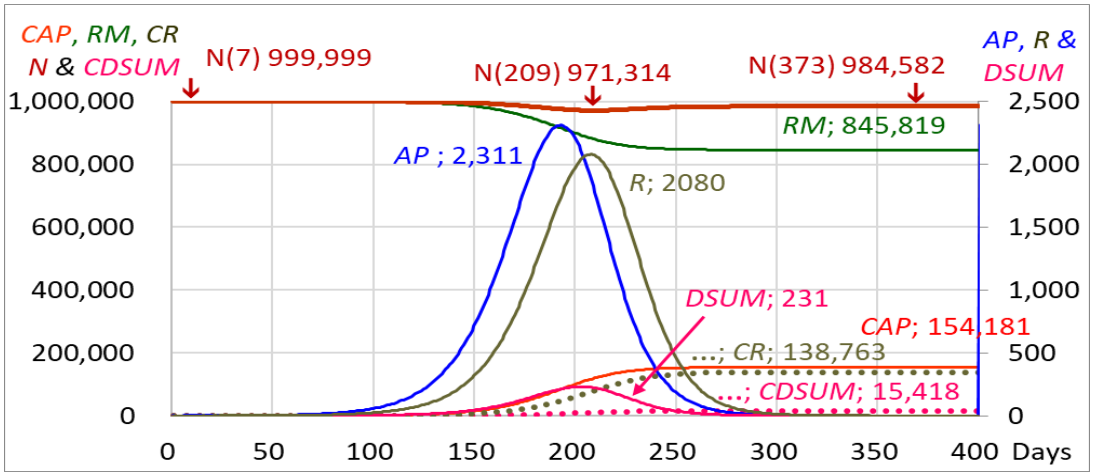

Figure 11: Changes in the current population of the 'real' community (*N*), the number of individuals infected a day (*AP*), the cumulative number of infected individuals (*CAP*), the number of deaths a day (*DSUM*), the cumulative number of deaths (*CDSUM*), the number of susceptible individuals (*RM*), the number of recovered individuals a day within the community (*R*; *RAS*) and the cumulative number of recovered individuals (*CR*) in the flexible compartment model. **The fatality rate is 0.1.** The community population is 1,000,000, where the potential (biological) infectious capacity of coronavirus (*pfc*) is 1.0, the latent period (*lp*) is 5, the recovery period (*rp*) is 14, the symptomatic rate (*syr*) is 1, *AL* is 1 and the value of *N* (*n*) is the current population, excluding both the number of isolated individuals and the number of deaths but including the number of recovered individuals; these values are given by $N(n)=TN(n\text{-}1)-(CI(n\text{-}1)+CPI(n\text{-}1)+CDSUM(n\text{-}1))+CRI(n\text{-}1)+CRT(n\text{-}1)$.

If the fatality rate (*frI*) is 1.0 (100%), that is, when all infected individuals die on the 10th day after infection, the number of individuals infected a day (*AP*) increases to a peak of 9,387 on day 227 and then decreases to 0 on day 706. The number of infected individuals (*P*) increases to a peak of 65,599 on day 230 and then decreases to 0 on day 799. The total number of infected individuals reaches 1,000,000 on day 884. The number of deceased individuals (*D*) increases to a peak of 9,387 on day 237 and then decreases to 0 on day 716. The total number of deaths, *CDSUM*, reaches 1,000,000 on day 894, meaning that the community would disappear (Table 4, Figure 12).

As examined above, when the change in the number of infected individuals is calculated in cases where deaths occur among the infected individuals, the flexible compartment model indicates that the total number of infected individuals increases significantly with an increase in the fatality rate, that is, with an increase in the ratio of the number of deaths of infected individuals (Table 4, Figure 12).

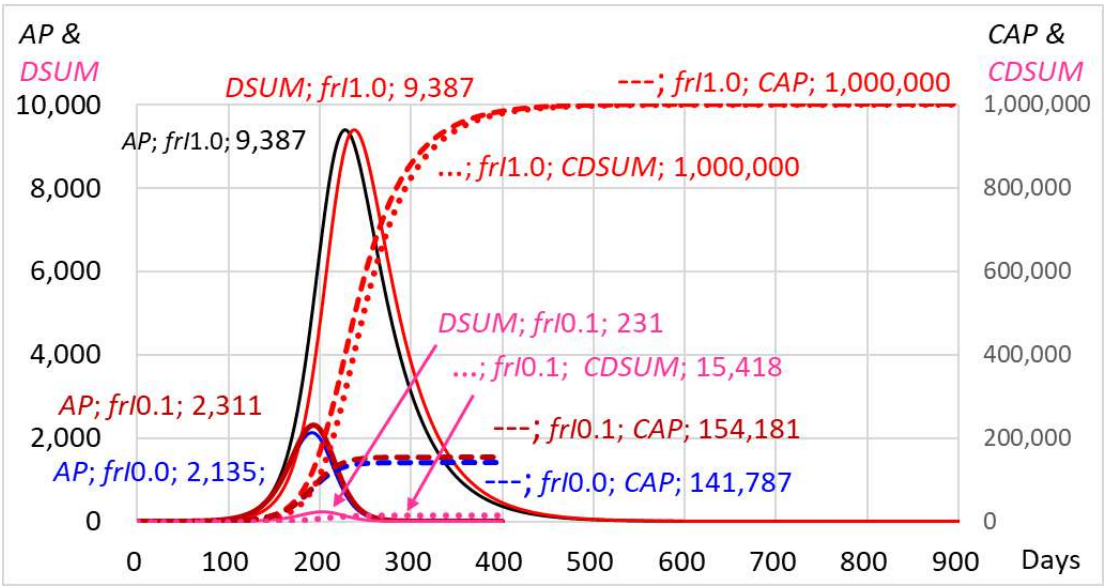

Figure 12: Comparison of *AP* (the number of individuals infected a day), *CAP* (the cumulative number of infected individuals), *DSUM* (the number of deaths a day) and *CDSUM* (the cumulative number of deaths) in cases with fatality rates (*frI*) of 0.0, 0.1 and 1.0. The flexible compartment model indicates that the total number of infected individuals increases with an increase in the fatality rate, that is, with an increase in the ratio of the number of deaths of infected individuals.

As previously noted, when death occurs, the number of "spreaders" decreases, but in a flexible compartment model, the number of recovered individuals (*RM*) also decreases, reducing the "contact rate reduction effect by recovered individuals," which increases the contact rate between infected individuals and susceptible individuals (see Eq. (1)), resulting in an increase in the total number of infected individuals (Figure 13). Furthermore, when deaths occur, since the population of the 'real community' (*N*) decreases, increasing the contact rate (see Eq. (1)) and increasing the infection coefficient (the infectious capacity) (see Eq. (23)), the increase in the total number of infected individuals is intensified.

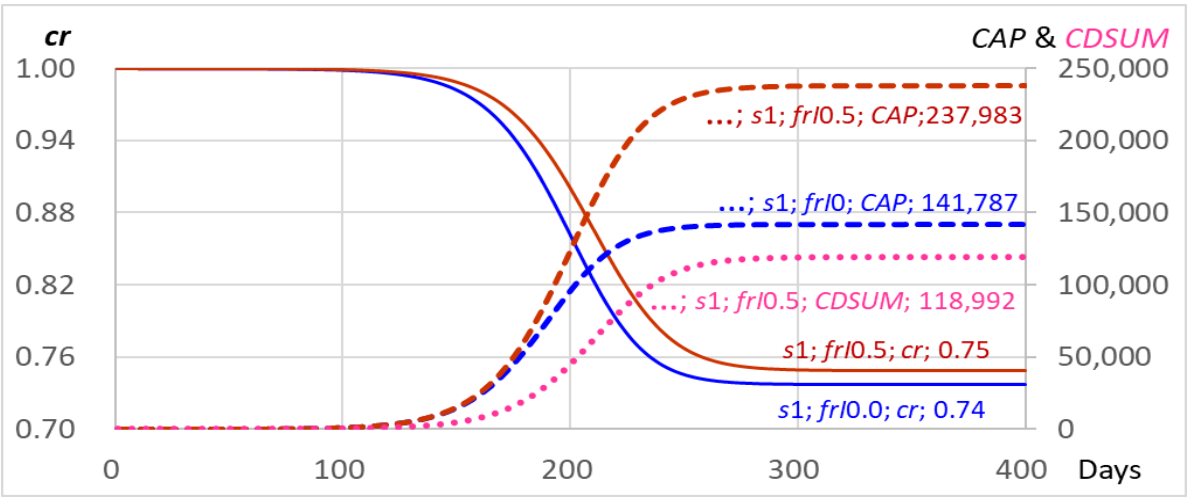

Figure 13: Changes in the contact rate (*cr*), the cumulative number of infected individuals (*CAP*) and the cumulative number of deaths (*CDSUM*) in the flexible compartment model, showing the difference when the fatality rate (*frI*) is 0 and 0.5. When deaths occur among infected individuals (*frI*0.5), the contact rate increases compared to when there are no deaths (*frI*0), and the total number of infected individuals increases. A symptomatic rate of 1.0 indicates that all infected individuals develop symptoms and are isolated.

When the symptomatic rate is set to 1.0, that is, when all infected individuals are isolated, the total number of infected individuals is significantly lower than when the symptomatic rate is 0.0, with all infected individuals remaining in the community (Tables 3 and 4). For example, when the symptomatic rate is set to 1.0 and the fatality rate (*frI*) is 0, the total number (*TI*) of infected individuals is 141,788. However, when the symptomatic rate was set to 0 and the fatality rate (*fr*) was 0, the total number (*TI*) of infected individuals increased to 598,287 (Table 4, 3, Figure 14).

However, even when the symptomatic rate is 1, the total number of infected individuals increases markedly with the increase in fatality rate among isolated individuals, and if the fatality rate (*frI*) is set to 1, it reaches one million (Table 4, Figure 14). This fact indicates that when an epidemic occurs, caring for infected individuals by isolating them, providing care, aiding in their recovery, and returning them to the community are critical measures for controlling the disease.

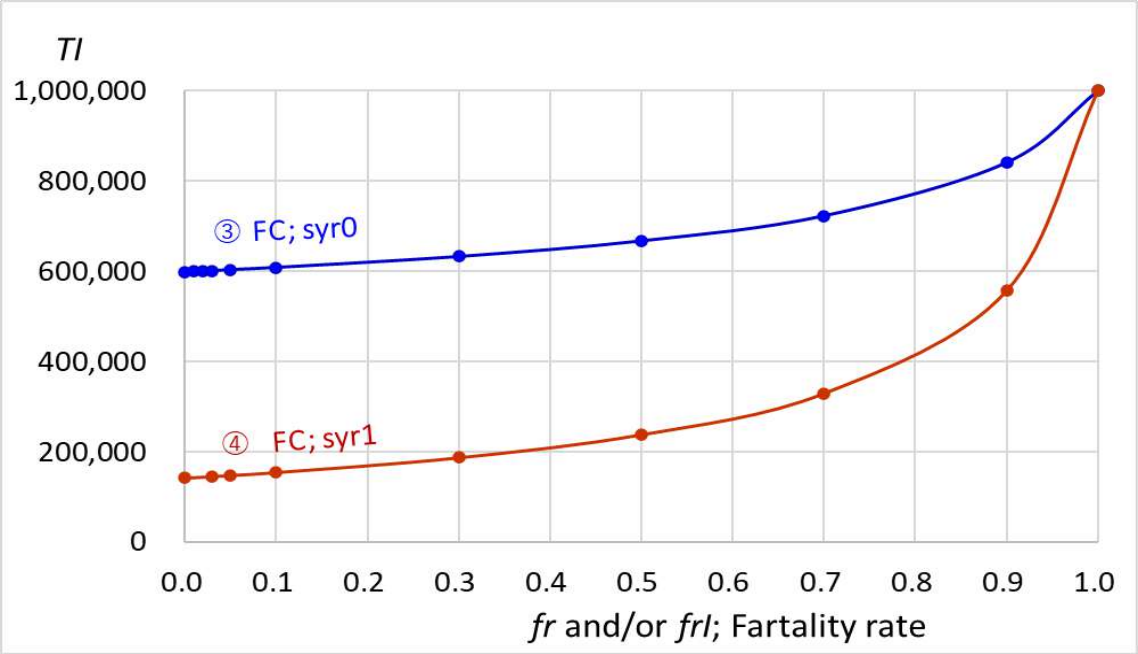

Figure 14: Comparison of the total number of infected individuals (*TI*) between symptomatic rates (*syr*) of 0 (③) and 1 (④) according to differences in fatality rates (*fr* for *syr* is 0 and *frI* for *syr* is 1) in the flexible compartment model (FC model). Even when the symptomatic rate is 1.0, the total number of infected individuals increases markedly with the increase in the fatality rate (*frI*) among isolated individuals, and when the fatality rate is set to 1.0, it reaches one million.

5.2.2. Change in the total number of infected individuals due to differences in case fatality rates for the symptomatic rate of 0.5

When the symptom rate is set to 0.5, half of the infected individuals develop symptoms on the day after the end of the latent period and are isolated the next day; excluding the deceased individuals, the individuals will recover on the day after the end of the recovery period (isolation period) and then return to the community the next day. The remaining half of the infected individuals are not isolated even on the day after the end of the latent period because they are asymptomatic, they continue to infect in the community, and they, excluding the deceased individuals, become recovered individuals on the day after the end of the recovery period. The current population of the community ($N(n)$) is the total population (initial population in this case) of the community minus the number of currently isolated individuals and the number of deaths but plus the number of recovered individuals who returned from isolation. Thus, as explained previously, the current population is given by Eq. (27'), that is, $N(n)=TN(n\text{-}1)-(CI(n\text{-}1)+CPI(n\text{-}1)+CDSUM(n\text{-}1))+CRI(n\text{-}1)+CRT(n\text{-}1)$, where $TN(n)$ is the total population of the community. When n is 1, i.e., the first day of simulation, N (1) is TN (1). $CI(n)$ is the cumulative number of isolated individuals due to testing positive, $CPI(n)$ is the cumulative number of isolated individuals due to being symptomatic, and $CDSUM$ (n) is the cumulative number of deaths. ($CRI(n)+CRT(n)$) indicates the total cumulative number of the cumulative number ($CRI(n)$) of recovered individuals who recovered from 'isolation due to positive results in the test' and the cumulative number ($CRT(n)$) of recovered individuals who returned from 'isolation due to symptom onset'. The number of recovered individuals a day within the community, $RAS(n)$, is already included in $N(n)$.

Then, the changes in the number of infected individuals were examined for cases when isolated infected individuals died and when infected individuals remaining in the community died.

When both the fatality rate (*frI*) for the isolated infected individuals and the fatality rate (*fr*) for the infected individuals remaining in the community are 0, that is, when any death does not occur, the number of individuals infected a day (*AP*) increases to a peak of 16,342 on day 97 and then decreases to 0 on day 176. The number of infected individuals (*P*) increases to a peak of 173,623 on day 103 and then decreases to 0 on day 200, with a total number (*TI*) of infected individuals of 490,235 (Table 5). This total number, 490,235, of infected individuals is significantly more by 348,448 compared to 141,787 when the symptomatic rate is set to 1.0 (Table 4), indicating that differences in symptomatic rates, that is, differences in isolation rates, have a significant effect on the occurrence of infections.

FC	Infected/day: *AP*			Infected: *P*			*TI*	*RM*	*CDSUM*	*CDSUM* ratio	Defference from *fr*/*frI*0	Increase ratio
pfc 1, *lp* 5, *rp* 14, *syr* 0.5, *AL* 1	Date of peak	Number	Date of end	Date of peak	Number	Date of end						
***fr* 0.0, *frI* 0.0**	97	16,342	176	103	173,623	200	490,235	509,765	0	0.000		
***fr* 0.03 *frI* 0.03**	98	16,342	177	103	172,714	201	493,331	506,669	14,800	0.030	3,096	0.006
***fr* 0.05, *frI* 0.05**	98	16,355	178	104	172,279	201	495,471	505,529	24,774	0.050	5,236	0.011
***fr* 0.1, *frI* 0.1**	99	16,362	179	104	170,966	203	501,109	498,891	50,111	0.100	10,874	0.022
***fr* 0.3, *frI* 0.3**	102	16,476	188	107	166,391	211	528,836	471,164	158,651	0.300	38,601	0.078
***fr* 0.5, *frI* 0.5**	106	16,706	199	111	162,981	223	569,472	430,528	284,736	0.500	79,237	0.160
***fr* 0.7, *frI* 0.7**	111	17,155	218	116	161,267	243	636,677	363,323	445,674	0.700	146,442	0.292
***fr* 0.9, *frI* 0.9**	117	18,054	266	122	163,254	299	783,660	216,340	705,294	0.900	293,425	0.555
***fr* 1.0, *frI* 1.0**	121	18,837	384	126	166,972	460	1,000,000	0	1,000,000	1.000	509,765	1.040

Table 5: Comparisons of the number of infected individuals among cases with fatality rates of 0.0, 0.03 (3%), 0.05 (5%), 0.1 (10%), 1.0 (100%; all infected individuals died) and others. The calculations were carried out using the "flexible compartment model"; the *syr* (the symptomatic rate is 0.5 (half of the infected individuals are isolated from the community, and half of the infected individuals remain in the community). Similarly, *AL* (the activity level of the recovered individuals who are in the community is 1, which means the activity of the recovered individuals is equal to that of the susceptible individuals. Similarly, the current population of the community ($N(n)$) is the total population (initial population in this case) of the community minus the number of isolated individuals and the number of deaths but plus the number of recovered individuals; that is, as explained previously, $N(n)=TN(n\text{-}1)-(CI(n\text{-}1)+CPI(n\text{-}1)+CDSUM(n\text{-}1))+CRI(n\text{-}1)+CRT(n\text{-}1)$. *AP*: the number of newly infected individuals a day at the peak; *P*: the number of infected at the peak; *TI*: the total number of infected individuals; *RM*: the number of susceptible individuals; and *CDSUM*: the total number of deaths at the end of infection. The potential (biological) infectious capacity of coronavirus *pfc* (n) is 1.0, the latent period *lp* (n) is 5, and the recovery period *rp* (n) is 14. The initial number of infected individuals *P* (1) is 1, and the initial population of the community *TN* (1) is 1,000,000. The "*CDSUM* ratio" indicates the ratio of the total number of deaths (*CDSUM*) to the total number of infected individuals (*TI*), that is, the actual fatality rate. The results calculated using the flexible compartment model indicate that the total number of infected individuals (*TI*) increases as the ratio of the number of deaths (*CDSUM* ratio; the fatality rate) increases.

When both fatality rates are 0.1, that is, when 10% of both isolated infected individuals and infected individuals remaining in the community die, the number of individuals infected a day (*AP*) increases to a peak of 16,362 on day 99 and then decreases to 0 on day 179. The number of infected individuals (*P*) increases to a peak of 170,966 on day 104 and then decreases to 0 on day 203, with a total number (*TI*) of infected individuals of 501,109. The number of deaths (*D*) increases to a peak of 1,636 on day 109 and then decreases to 0 on day 188, and the total number of deaths, *CDSUM*, reaches 50,111 (Table 5).

When both fatality rates are 1.0, that is, when all of the isolated infected individuals and infected individuals remaining in the community die, the number of individuals infected a day (*AP*) increases to a peak of 18,837 on day 121 and then decreases to 0 on day 394. The number of infected individuals (*P*) increases to a peak of 166,972 on day 126 and then decreases to 0 on day 460, with a total number (*TI*) of infected individuals of 1,000,000. The number of deaths (*D*) increases to a peak of 18,837 on day 131 and then decreases to 0 on day 470, and the total number of deaths, *CDSUM*, reaches 1,000,000 (Table 5).

As examined above, the total number of infected individuals increases significantly with an increase in the fatality rate, that is, with an increase in the ratio of the number of deaths of infected individuals.

When the case fatality rate (*fr*) is 0, there will be no deaths among the infected individuals remaining in the community. Here, the change in the number of infected individuals is examined when the fatality rate of isolated infected individuals differs, that is, when *frI* is different.

When the fatality rate (*frI*) is 0, the change in the number of infected individuals is the same as when both *fr* and *frI* are 0, as shown in Table 5; the number of individuals infected a day (*AP*) increases to a peak of 16,342 on day 97 and then decreases to 0 on day 176. The number of infected individuals (*P*) increases to a peak of 173,623 on day 103 and then decreases to 0 on day 200, with a total number (*TI*) of infected individuals of 490,235 (Table 6).

FC	Infected/day: *AP*			Infected: *P*			*TI*	*RM*	*CDSUM*	*CDSUM* ratio	Defference from *frI* 0	Increase ratio
pfc 1, *lp* 5, *rp* 14, *syr* 0.5, *AL* 1	Date of peak	Number	Date of end	Date of peak	Number	Date of end						
***fr* 0.0, *frI* 0.0**	97	16,342	176	103	173,623	200	490,235	509,765	0	0.000		
***fr* 0, *frI* 0.03**	97	16,411	176	103	174,404	200	493,121	506,879	7,397	0.015	2,886	0.0059
***fr* 0, *frI* 0.05**	97	16,457	177	103	174,927	200	495,068	504,932	12,377	0.025	4,833	0.0099
***fr* 0, *frI* 0.1**	97	16,574	177	103	176,244	201	500,019	499,981	25,001	0.050	9,784	0.0200
***fr* 0, *frI* 0.3**	98	17,077	180	104	181,761	204	521,116	478,884	78,167	0.150	30,881	0.0630
***fr* 0, *frI* 0.5**	98	17,617	183	104	187,833	207	544,608	455,392	136,152	0.250	54,373	0.1109
***fr* 0, *frI* 0.7**	98	18,177	186	104	194,172	211	571,060	428,940	199,871	0.350	80,825	0.1649
***fr* 0, *frI* 0.9**	99	18,796	191	105	201,157	216	601,277	398,724	270,575	0.450	111,042	0.2265
***fr* 0, *frI* 1.0**	99	19,172	193	105	204,858	219	618,153	381,847	309,077	0.500	127,918	0.261

Table 6: Comparisons of the number of infected individuals among cases with fatality rates of 0.0, 0.03 (3%), 0.05 (5%), 0.1 (10%), 1.0 (100%; all infected individuals died) and others. The fatality rate (*fr*) of infected individuals remaining in the community is set to 0. The calculations were carried out using the "flexible compartment model"; the *syr* (the symptomatic rate) is 0.5 (half of the infected individuals are isolated from the community, and half of infected individuals remain in the community). Similarly, *AL* (the activity level of the recovered individuals who are in the community) is 1, which means the activity of the recovered individuals is equal to that of the susceptible individuals. Similarly, the current population of the community ($N(n)$) is the total population (initial population in this case) of the community minus the number of isolated individuals and the number of deaths but plus the number of recovered individuals, that is, $N(n)=TN(n\text{-}1)\text{-}(CI(n\text{-}1)+CPI(n\text{-}1)+CDSUM\,(n\text{-}1))+CRI(n\text{-}1)+CRT(n\text{-}1)$. *AP*: the number of newly infected individuals a day at the peak; *P*: the number of infected individuals at the peak; *TI*: the total number of infected individuals; *RM*: the number of susceptible individuals; and *CDSUM*: the total number of deaths at the end of infection. The potential (biological) infectious capacity of coronavirus *pfc* (*n*) is 1.0, the latent period *lp* (*n*) is 5, and the recovery period *rp* (*n*) is 14. The initial number of infected individuals *P* (1) is 1, and the initial population of the community *TN* (1) is 1,000,000. The "*CDSUM* ratio" indicates the ratio of the total number of deaths (*CDSUM*) to the total number of infected individuals (*TI*), that is, the actual fatality rate. The results calculated using the flexible compartment model indicate that the total number of infected individuals (*TI*) increases as the ratio of the number of deaths (*CDSUM* ratio; the fatality rate) increases.

When *frI* is 0.1, that is, when 10% of isolated infected individuals die, the number of individuals infected a day (*AP*) increases to a peak of 16,574 on day 97 and then decreases to 0 on day 177. The number of infected individuals (*P*) increases to a peak of 176,244 on day 103 and then decreases to 0 on day 201, with a total number (*TI*) of infected individuals of 500,019. The number of deaths (*D*) increases to a peak of 829 on day 107 and then decreases to 0 on day 180, and the total number of deaths, *CDSUM*, reaches 25,001 (Table 6).

When *frI* is 1.0, that is, when all isolated infected individuals die, the number of individuals infected a day (*AP*) increases to a peak of 19,172 on day 99 and then decreases to 0 on day 193. The number of infected individuals (*P*) increases to a peak of 204,858 on day 105 and then decreases to 0 on day 219, with a total number (*TI*) of infected individuals of 618,153. The number of deaths (*D*) increases to a peak of 9,561 on day 109 and then decreases to 0 on day 219, and the total number of deaths, *CDSUM*, reaches 309,077 (Table 6).

As shown above, the total number of infected individuals increases with an increase in the fatality rate (*frI*), that is, with an increase in the ratio of the number of deaths of infected individuals. However, the "increase ratio" is smaller than that when deaths occur for both isolated infected individuals and infected individuals remaining in the community (Tables 6 and 5).

When the fatality rate *frI* is 0, there will be no deaths among isolated infected individuals. Here, the change in the number of infected individuals is examined when the fatality rate of infected individuals remaining in the community differs, that is, when *fr* is different.

When the fatality rate *fr* is 0, the change in the number of infected individuals is the same as when there are no deaths in either isolated infected individuals or infected individuals remaining in the community, that is, when both *fr* and *frI* are 0 (Table 7).

FC	Infected/day: *AP*			Infected: *P*			*TI*	*RM*	*CDSUM*	*CDSUM* ratio	Defference from *fr* 0	Increase ratio
pfc 1, *lp* 5, *rp* 14, *syr* 0.5, *AL* 1	Date of peak	Number	Date of end	Date of peak	Number	Date of end						
***fr* 0.0, *frI* 0.0**	97	16,342	176	103	173,623	200	490,235	509,765	0	0.000		
***fr* 0.03, *frI* 0.0**	98	16,268	177	103	171,949	200	490,400	509,600	7,356	0.015	165	0.0003
***fr* 0.05, *frI* 0.0**	98	16,233	177	104	170,921	201	490,509	509,491	12,263	0.025	274	0.0006
***fr* 0.1, *frI* 0.0**	99	16,106	178	104	168,329	202	490,782	509,218	24,539	0.050	547	0.0011
***fr* 0.3, *frI* 0.0**	101	15,634	183	107	157,700	206	491,849	508,151	73,777	0.150	1,614	0.0033
***fr* 0.5, *frI* 0.0**	105	15,109	189	110	146,909	211	492,867	507,133	123,217	0.250	2,632	0.0054
***fr* 0.7, *frI* 0.0**	109	14,521	195	113	135,891	217	493,815	506,185	172,835	0.350	3,580	0.0073
***fr* 0.9, *frI* 0.0**	113	13,871	202	118	124,562	223	494,684	505,316	222,608	0.450	4,449	0.0091
***fr* 1.0, *frI* 0.0**	116	13,513	206	120	118,807	226	495,096	505,904	247,548	0.500	4,861	0.010

Table 7: Comparisons of the number of infected individuals among cases with fatality rates of 0.0, 0.03 (3%), 0.05 (5%), 0.1 (10%), 1.0 (100%; all infected individuals died) and others. The fatality rate for isolated infected individuals (*frI*) is set to 0. The calculations were carried out using the "flexible compartment model" ; the *syr* (the symptomatic rate) is 0.5 (half of infected individuals are isolated from the community, and half of the infected individuals remain in the community), *AL* (the activity level of the recovered individuals who are in the community) is 1, which means the activity of the recovered individuals is equal to that of the susceptible individuals. Similarly, the current population of the community ($N(n)$) is the total population (initial population in this case) of the community minus the number of isolated individuals and the number of deaths but plus the number of recovered individuals, that is, $N(n)=TN(n\text{-}1)-(CI(n\text{-}1)+CPI(n\text{-}1)+CDSUM(n\text{-}1))+CRI(n\text{-}1)+CRT(n\text{-}1)$. *AP*: the number of newly infected individuals a day at the peak; *P*: the number of infected individuals at the peak; *TI*: the total number of infected individuals; *RM*: the number of susceptible individuals; and *CDSUM*: the total number of deaths at the end of infection. The potential (biological) infectious capacity of coronavirus *pfc* (*n*) is 1.0, the latent period *lp* (*n*) is 5, and the recovery period *rp* (*n*) is 14. The initial number of infected individuals *P* (1) is 1, and the initial population of the community *TN* (1) is 1,000,000. The "*CDSUM* ratio" indicates the ratio of the total number of deaths (*CDSUM*) to the total number of infected individuals (*TI*), that is, the actual fatality rate. The results calculated using the flexible compartment model indicate that the total number of infected individuals (*TI*) increases as the ratio of the number of deaths (*CDSUM* ratio; the fatality rate) increases.

When *fr* is 0.1, that is, when 10% of infected individuals remaining in the community die, the number of individuals infected a day (*AP*) increases to a peak of 16,106 on day 99 and then decreases to 0 on day 178. The number of infected individuals (*P*) increases to a peak of 168,329 on day 104 and then decreases to 0 on day 202, with a total number (*TI*) of infected individuals of 490,782. The number of deaths (*D*) increases to a peak of 805 from day 107 to day 109 and then decreases to 0 on day 179, and the total number of deaths, *CDSUM*, reaches 24,539 (Table 7).

When *fr* is 1.0, that is, when all infected individuals remaining in the community die, the number of individuals infected a day (*AP*) increases to a peak of 13,513 on day 116 and then decreases to 0 on day 206. The number of infected individuals (*P*) increases to a peak of 118,807 on day 120 and then decreases to 0 on day 226, with a total number (*TI*) of infected individuals of 495,096. The number of deaths (*D*) increases to a peak of 6,756 on day 126 and then decreases to 0 on day 225, and the total number of deaths, *CDSUM*, reaches 247,548 (Table 7).

As examined above, although the 'increase ratio' (Table 7) is significantly lower than that when deaths occur in both isolated infected individuals and those remaining in the community (Table 5) and when deaths occur only in isolated infected individuals (Table 6), the total number of infected individuals (*TI*) increases with an increase in the fatality rate (*fr*), that is, with an increase in the ratio of the number of deaths among infected individuals remaining in the community. The reason "the increase ratio is small" is that 'half of the infected individuals are isolated, all of those isolated infected individuals recover and return to the community.'

In addition, as seen when the fatality rate was 0.0, the total number of infected individuals for a symptomatic rate (*syr*) of 0.5 was greater than that for symptomatic rate of 1.0 (all infected individuals isolated; ④) but lower than that for symptomatic rate (*syr*) of 0.0 (all infected individuals remaining in the community; ③) (Figure 15). Namely, as noted by Ohmori (2023) [17], it can be seen that "when the number of isolated individuals increases, that is, when the symptomatic rate (*syr*) increases, the number of infected individuals (*TI*) is reduced" (Figure 15). This indicates that "isolating more infected individuals, reducing the deaths of those isolated infected individuals, recovering more isolated infected individuals and returning them to the community" is a significantly effective measure for controlling the spread of infection.

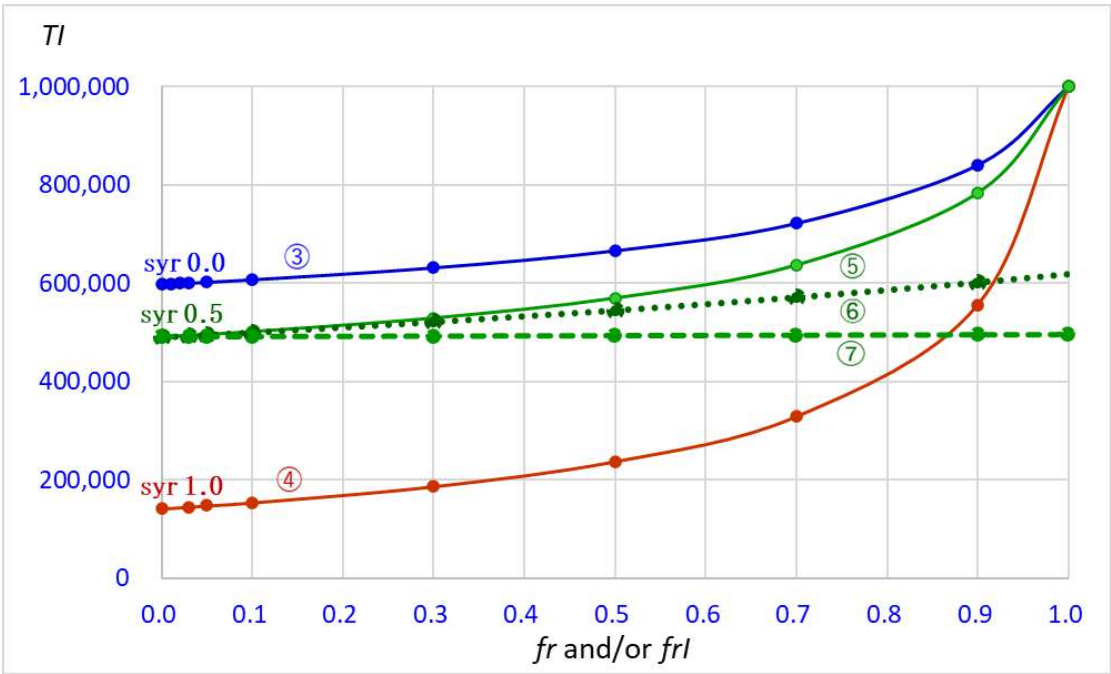

Figure 15: Comparison of the total number of infected individuals (*TI*) according to differences in mortality rates between cases in which deaths occurred both in isolated individuals and in community-infected individuals (⑤), case where deaths occurred only in isolated individuals (⑥), and case where deaths occurred only in community-infected individuals (⑦). In addition, when the symptomatic rate was 0.5, half of the infected individuals were isolated, and the remaining half stayed in the community. Line ③ represents the case with a symptomatic rate of 0.0 (all infected individuals remain in the community), and line ④ represents the case with a symptomatic rate of 1.0 (all infected individuals are isolated).

5.3. Effect of deaths on the spread of COVID-19 when reinfections occur

As mentioned previously (in section **4.3. "Change in the number of individuals getting back to susceptible individuals from recovered individuals"**), individuals who have been infected with COVID-19 and have recovered will return to the community as individuals who have infection-induced immunity after the recovery period ends. However, infection-induced immunity has a duration that indicates the 'validity period of effectiveness of immunity against COVID-19 disease'. In other words, the quantity of antibodies acquired through infection gradually wanes and eventually declines below a certain threshold of immunity level, below which recovered individuals could become infected again. Specifically, individuals whose duration of infection-induced immunity ends substantially get back to 'susceptible individuals' who could be infected, and some of them should become reinfected. In the case of COVID-19, reinfections not only occur in susceptible individuals who have got back from recovered individuals but also inevitably induce infections (the first infections, normal infections) in originally susceptible individuals; as a result, multiple waves of epidemics (outbreaks) occurred as pointed by Ohmori (2025) [20]. In this section, the **e**ffect of deaths on the spread of COVID-19 in a case where reinfections occur is examined.

As previously noted, in section **4.2. "Calculation of the number of infected individuals, the number of individuals newly infected a day, the number of recovered individuals and the 'population of the real community"**, the fatality rates are usually less than a few percent, such as 0.05 (5%) or 0.01 (1%), or even lower. To deal with this small fatality rate, in this article, the calculations use decimal values as they are.

Now, consider a case where the community population is 1,000,000 and where the potential (biological) infectious capacity of coronavirus (*pfc*) is 1.0, the latent period (*lp*) is 5, the recovery period (*rp*) is 14, the symptomatic rate (*syr*) is 1 and *AL* is 1.

Whether reinfection occurs depends on the duration of infection-induced immunity (the validity period of infection-induced immunity), and the duration of infection-induced immunity required for reinfection to occur varies depending on the symptomatic rate (*syr*) and the potential infectious capacity of coronavirus (*pfc*). And it is known that, when the symptomatic rate is 1.0 and the potential infectious capacity of coronavirus is also 1.0, if the duration of infection-induced immunity (*dii*) is 156 days, reinfection does not occur, but if the *dii* is less than 155, reinfection occurs (Ohmori (2025) [20]). Therefore, the case where the duration of infectious immunity (*dii*) is 150 is examined.

When the symptomatic rate is set to 1.0, all infected individuals develop symptoms on the day after the end of the latent period and are isolated the next day, and, excluding the deceased individuals, they become recovered individuals on the day after the end of the recovery period (isolation period) and return to the community the next day. The current population of the community ($N(n)$) is the total population of the community minus the number of isolated individuals and the number of deaths but plus the number of recovered individuals; that is, as explained previously, $N(n)=TN(n\text{-}1)-(CI(n\text{-}1)+CPI(n\text{-}1)+CDSUM(n\text{-}1))+CRI(n\text{-}1)+CRT(n\text{-}1)$, where $TN(n)$ is the total population of the community. When n is 1, i.e., the first day of simulation, $N(1)$ is $TN(1)$. $CI(n)$ is the cumulative number of isolated individuals due to positive in test, $CPI(n)$ is the cumulative number of isolated individuals due to being

symptomatic, and (*DSUM* (*n*) is the cumulative number of deaths. (*CRI*(*n*)+*CRT*(*n*)) indicates the total cumulative number of the cumulative number (*CRI*(*n*)) of recovered individuals who returned from 'isolation due to positive in test' and the cumulative number (*CRT*(*n*)) of recovered individuals who returned from 'isolation due to symptom onset'.

When the duration of infection-induced immunity (*dii*) is set to 0, which means that the validity period of infection-induced immunity is permanent, and the fatality rate (*frI*) is also set to 0, reinfection does not occur, and no deaths also occur. In this case, as shown previously (in section **5.2.1. "Change in the total number of infected individuals due to differences in case fatality rates for the symptomatic rate of 1.0"**), the number of individuals infected a day (*AP*) increases to a peak of 2,135 on days 191 and 192 and then decreases to 0 on day 326. The number of infected individuals (*P*) increases to a peak of 14,895 on day 194 and then decreases to 0 on day 354, with a total number (*TI*) of infected individuals of 141,787 (Tables 4 and 8).

frI	0.0	Epidemic 1	
dii	0	Peak	End
AP	Date	191-192	326
	Number	2,135	0
	CAP		141,782
P	Date	194	354
	Number	14,895	0
	CAP		141,787

frI	0.0	Epidemic 1		Epidemic 2		Epidemic 3		Epidemic 4		Epidemic 5		Epidemic 6		Epidemic 7	
dii	150	Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	End
AP	Date	191	336-381	566	712-757	957	1,109-1,146	1,353-1,354	1,521-1,532	1,745-1,749	1,919-1,936	2,139-2,147	2,331-2,358	2,552-2,556	7,206
	Number	2,136	0	1,999	0	1,474	1	905	6	490	24	238	51	107	0
	CAP		141,920		275,755		387,809		474,236		538,763		587,407		681,502
P	Date	194	349-372	569	727-746	960	1,127-1,132	1,356	1,524-1,535	1,750	1,927-1,933	2,144-2,148	2,344-2,351	2,556-2,559	8,947
	Number	14,898	2	13,942	2	10,288	8	6,324	45	3,429	169	1,665	356	746	0
	"*CAP* "	372	141,917	374	133,833	386	112,040	403	86,466	398	64,434	418	48,358	662	47,239
	CAP		141,917		275,750		387,790		474,256		538,690		587,048	"*CAP* (3013) 634,287"	681,884
frI	0.1	Epidemic 1		Epidemic 2		Epidemic 3		Epidemic 4		Epidemic 5		Epidemic 6		Epidemic 7	
dii	150	Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	End
AP	Date	193	342-377	565	716-751	956	1,098-1,157	1,353	1,522-1,533	1,747-1,751	1,930-1,936	2,149-2,152	2,351-2,386	2,543-2,594	6,705
	Number	2,136	0	2,120	0	1,502	2	871	8	439	30	196	56	82	0
	CAP		154,328		296,988		413,115		499,704		562,347		608,992		683,704
P	Date	196	345-380	568	720-754	959	1,118-1,141	1,356	1,525-1,535	1751-1,753	1,934-1,938	2,151-2,156	2,365-2,377	2,563-2,580	8,303
	Number	16,125	3	14,089	3	10,483	11	6,084	59	3,071	213	1,368	391	577	0
Peri(days)& "*CAP* "		380	154,330	374	142,659	387	116,093	395	86,639	403	62,587	439	46,178	686	41,480
	CAP		154,330		296,989		413,082		499,721		562,308		608,486	"*CAP* (3063) 649,966"	684,055
DSUM	Date	202-204	311-437	574-576	684-816	964-968	1,091-1,189	1,360-1,367	1,498-1,583	1,753-1,765	1,915-1,974	2,155-2,166	2,321-2,453	2,504-2,657	7,445
	Number	231	0	212	0	150	0	87	1	44	3	20	6	8	0
Peri(days)& "*CD* "		430	15,442	379	14,267	373	11,610	394	8,695	583	6,301	479	4,927	753	4,257
	CDSUM		15,442		29,709		41,319		50,014		56,315		61,242	"*CD* (3206) 65,499"	68,395

Table 8: Changes in the number of individuals infected a day (*AP*), the number of infected individuals (*P*), the cumulative number of infected individuals (*CAP*), the number of deaths a day (*DSUM*) and the cumulative number of deaths (*CDSUM*). The "Peri (days)" indicates the period of each epidemic, the "*CAP*" indicates the total number of infected individuals for each epidemic, and "*CD*" indicates the total number of deaths for each epidemic. The "*CAP* (3013) 684,287" indicates that the cumulative number of infected individuals (*CAP*) reaches 684,287 on day 3,013 when the change in infected individuals shows a "temporary calm" (see Figure 16-b). This "temporary calm" is recognized as the "end of the seventh epidemic" compared to other epidemics. The "*CAP* (3,063) 649,966" and the "*CD* (3,206) 65,499" also have the same meanings as above. The symptomatic rate is 1.0. The current population of the community (*N*(*n*)) is given by subtracting the number of infected individuals kept in isolation and the number of deaths from the initial population of the community and adding the number of recovered individuals; that is, *N*(*n*)=*TN*(*n*-1)-(*CI*(*n*-1)+*CPI*(*n*-1)+*CDSUM*(*n*-1)) +*CRI*(*n*-1)+*CRT*(*n*-1). The variable '*dii*' is the duration of infection-induced immunity (the validity period of infection-induced immunity), and the '*frI*' is the fatality rate for isolated infected individuals. The numeral in the *P* (*n*) line of the 'End' column indicates the day when the number of infected individuals *P* (*n*) becomes 0, which signifies the "endo of the duration of infection" in this article. When *dii* is 150 days, "reinfections" induce 7 epidemics (outbreaks). The potential (biological) infectious capacity of coronavirus *pfc* (*n*) is 1.0, the latent period *lp* (*n*) is 5, and the recovery period *rp* (*n*) is 14. The initial number of infected individuals *P* (1) is 1, and the initial population of the community *TN* (1) is 1,000,000.

Under a condition where *dii* is set to 150 days and reinfection occurs, for two cases, that is, for one where the fatality rate (*frI*) is set to 0.0 and no deaths occur, and for another where *frI* is set to 0.1 and 10% of isolated infected individuals die, the changes in the number of individuals infected a day (*AP*), the number of infected individuals (*P*), the cumulative number of infected individuals (*CAP*), the number of deaths a day (*DSUM*), and the cumulative number of deaths (*CDSUM*) were calculated. These results are shown in Table 8 and Figures 16-a, b, and c.

The date and number of infected individuals at the peak of *AP* differ slightly between when *frI* is 0.0 and when *frI* is 0.1. The period of each epidemic also differs slightly between when *frI* is 0.0 and when *frI* is 0.1, but the difference is not very large. The peak number of individuals infected a day (*AP*) during each epidemic and the "total number of infections in each epidemic (*CAP*)" steadily decrease in both cases, whether *frI* is 0.0 or *frI* is 0.1.

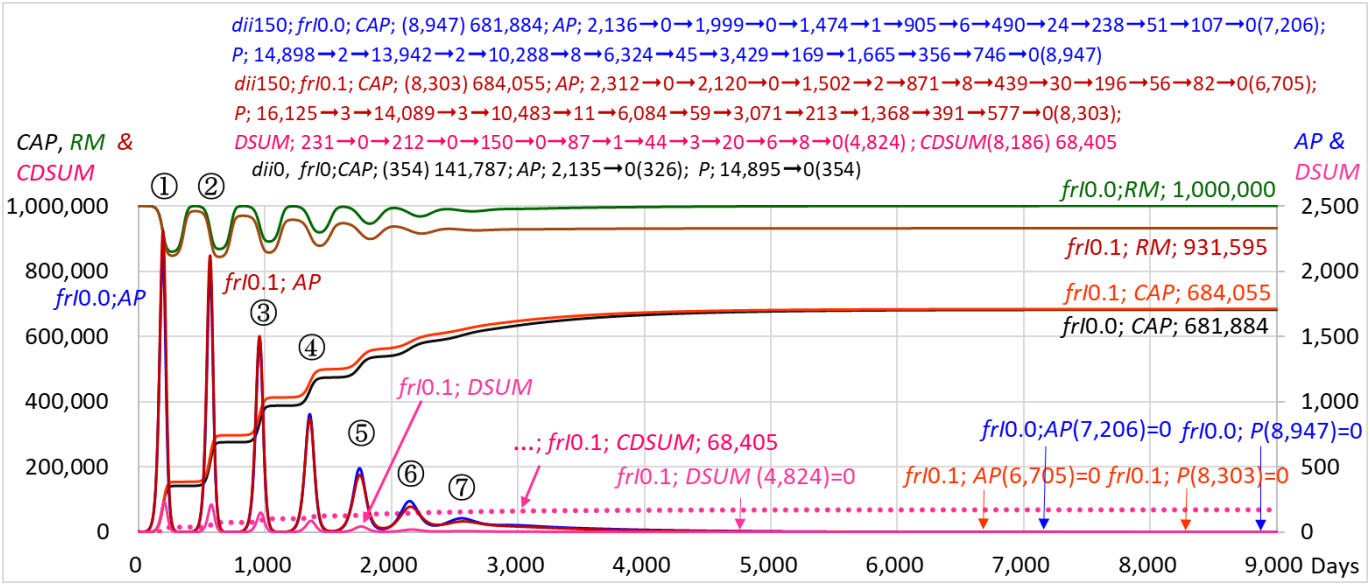

Figure 16-a: Changes in the number of individuals infected a day (*AP*), the number of infected individuals (*P*), the cumulative number of infected individuals (*CAP*), the number of deaths a day (*DSUM*), the cumulative number of deaths (*CDSUM*) and the number of susceptible individuals (*RM*). ① ~ ⑦: the first epidemic ~ the seventh epidemic. The term "*frI*0.0; *AP* (7,206) =0" indicates that when the fatality rate (*frI*) of isolated infected individuals is 0.0, the number of individuals infected a day (*AP*) becomes 0 on day 7,206. The "*frI*0.1; *AP* (6,705) =0" and the like also have the same meaning.

Concerning the seventh epidemic (outbreak, ⑦), the date of the end is not clear in Figure 16-a. However, in Figure 16-b, where the changes in *AP* and *DSUM* during the seventh epidemic expanded, the end date of the seventh epidemic can be recognized. That is, in Figure 16-b, the term "*frI*0.0; *AP* (3,013) 53" indicates that the 3,013th day represents the last day on which the number of individuals infected per day (*AP*) was maintained at 53, and it is clearly recognizable that the change in *AP* shows a 'temporary calm' just before a relatively rapid decrease. This "temporary calm" is recognized as the "end of the seventh epidemic" compared to other epidemics. Similarly, "*frI*0.1; *AP* (3,063) 41" and "f*rI*0.1; *DSUM* (3,206) 41" also indicate "the end of the seventh epidemic." The total number of infected individuals ("*CAP*") and the total number of deaths ("*CD*") during the seventh epidemic are shown in Table 8. As previously noted, "the number of infected individuals at the peak of *AP* is steadily decreasing," and the 'total number of infected individuals ("*CAP*") for each epidemic is also steadily decreasing in both cases, whether *frI* is 0.0 or 0.1. The 'total number of deaths ("*CD*")' for each epidemic also steadily decreases.

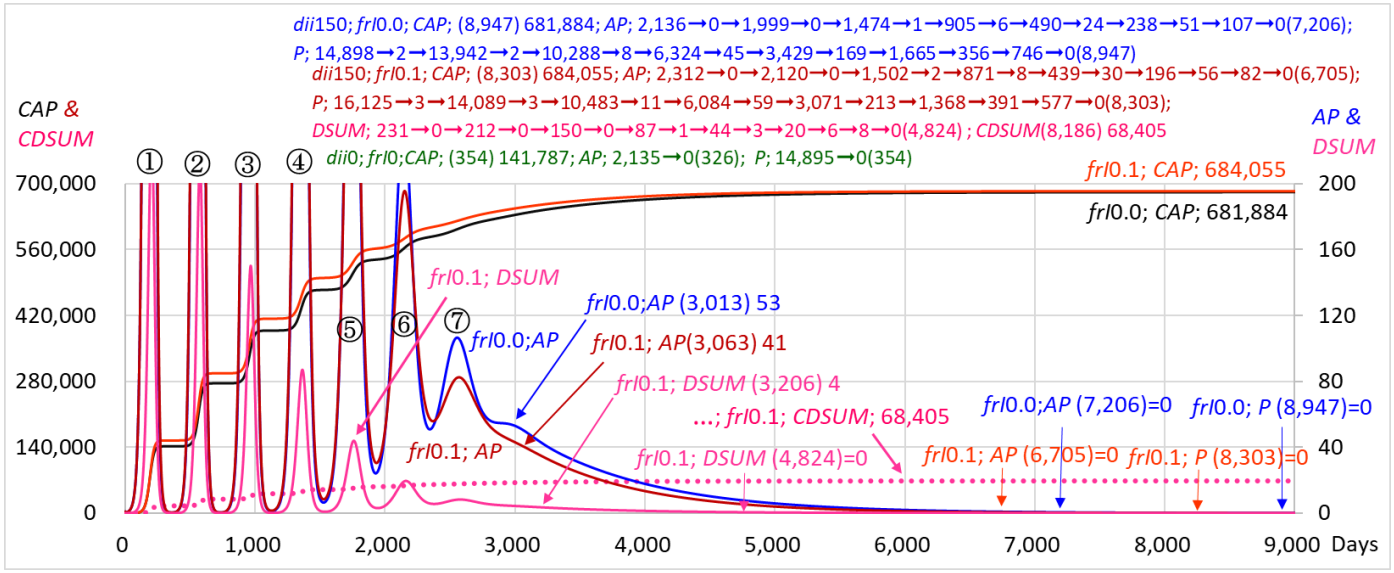

Figure 16-b: Changes in the number of individuals infected a day (*AP*), the number of infected individuals (*P*), the cumulative number of infected individuals (*CAP*), the number of deaths a day (*DSUM*) and the cumulative number of deaths (*CDSUM*). The term "*frI*0.0; *AP* (3,013) 53" indicates that the number of infected individuals a day (*AP*) was 53 on day 3,013, when the change in *AP* was considered "temporary calm". This "temporary calm" is recognized as the "end of the seventh epidemic" compared to other epidemics. The "*frI*0.1; *AP* (3,063) 41" and the "*frI*0.1; *DSUM* (3,206) 41" also have the same meanings as above.

As previously noted, the number of individuals infected a day at the peak of each epidemic, that is, the peak number of *AP* in each epidemic, steadily decreases with epidemic in both cases, whether *frI* is 0.0 or 0.1. However, when *frI* is 0.1, the initially large peak number of individuals infected a day rapidly decreases. The 'peak number of *AP*' and the 'total number of infected individuals ("*CAP*")' for each epidemic are greater when *frI*=0.1 than when *frI*=0.0 up to the third epidemic; the numbers became almost the same in the fourth epidemic and reversed from the fifth epidemic onward; that is, the 'peak number of *AP*' and the 'total number of infected individuals ("*CAP*")' for each epidemic became greater when *frI*=0.0 than when *frI*=1.0 (Table 8, Figure 16-c). At first glance, it may seem that the 'effect of an increase in infections due to the occurrence of deaths' has disappeared, but it is important not to misunderstand this.

In other words, this is due to a kind of numerical magic as follows: when deaths do not occur (*frI*0.0), all infected individuals recover and eventually get back to susceptible individuals (*RM*). On the other hand, when death occurs, the deceased individual is removed from the community, so the number of recovered individuals is reduced; as a result, the number of susceptible individuals (*RM*) decreases due to an increase in the cumulative number of deaths (*CDSUM*). For example, in the fifth epidemic, the number of susceptible individuals for a fatality rate of 0.1 decreased to 947,133, which is 50,340 fewer than the 997,473 for a fatality rate of 0.0. As a result, both of the peak number of infected individuals a day (*AP*) and the total number of infected individuals ("*CAP*") during the fifth epidemic became less than when *frI* was 0.0. As explained here, if the dynamics of the number of susceptible individuals are not considered, this can be misleading.

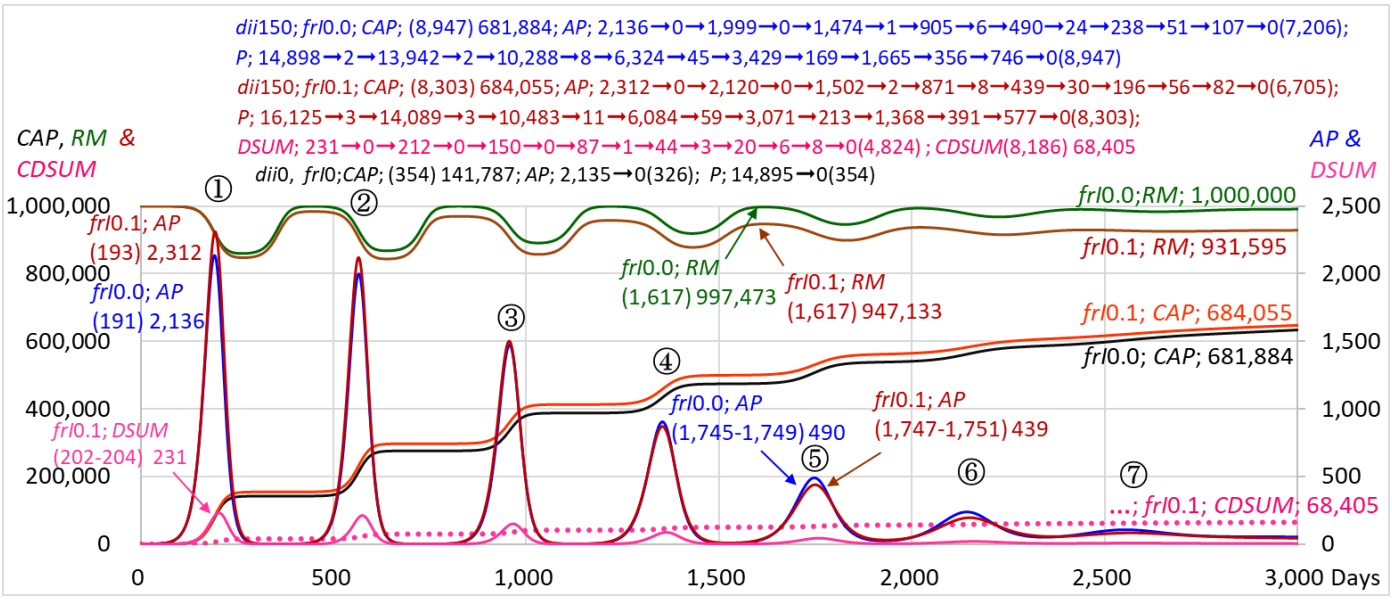

Figure 16-c: Changes in the number of individuals infected a day (*AP*), the number of infected individuals (*P*), the cumulative number of infected individuals (*CAP*), the number of deaths a day (*DSUM*), the cumulative number of deaths (*CDSUM*) and the number of susceptible individuals (*RM*). The "*frI*0.0; *AP* (191) 2,136" indicates that the number of infected individuals a day (*AP*) was 2,136 on day 191. The "*frI*0.0; *DSUMP* (202-204) 231" indicates that the number of deaths a day (*DSUM*) between day 202 and day 204 is 231. The "*frI*0.1; *AP* (193) 2,312" and the like also have the same meaning. When deaths do not occur (*frI*0.0), all infected individuals recover and eventually get back to susceptible individuals (*RM*). On the other hand, when deaths occur, the deceased individuals are removed from the community, so the number of susceptible individuals (*RM*) is reduced by the cumulative number of deaths (*CDSUM*). For example, in the fifth epidemic (⑤), the number of susceptible individuals for a fatality rate of 0.1 decreased to 947,133, which is 50,340 fewer than the 997,473 for a fatality rate of 0.0. As a result, the peak number of infected individuals a day (AP) and the total number of infected individuals ("CAP") during the fifth epidemic also decreased.

As previously mentioned, in this article, the duration of infection ends on the day when the number of infected individuals (*P*) reaches 0. As shown in Table 8 and in Figures 16-a and b, the duration of infection was 8,303 days when death occurred (*frI*=0.1) was shorter than 8,947 days when death did not occur (*frI*=0.0). However, the final total number of infected individuals at the end of the infection becomes certainly greater when deaths occur (684,055 total number of infected individuals) than when deaths do not occur (681,884 total number of infected individuals) (Table 8, Figures 16-a and b).

6. Summary of the simulation results

In this article, the cases where the initial population of the community (*TN*) is 1,000,000, the potential (biological) infectious capacity of coronavirus (the infectivity coefficient; *pfc*) is 1.0, the latent period (*lp*) is 5, and the recovery period (*rp*) is 14 were considered.

1. According to the SIRD model, all infected individuals stay in the community, and both deceased and recovered individuals are excluded from the community, but the population of the community (*N*(*n*)) remains constant: 'susceptible (*S*) + infected (*I*) + recovered (*R*) + dead (*D*)'. When the fatality rate (*fr*) is 0, that is, when any deaths do not occur, the total number of infected individuals (*TI*) reaches 674,892 on day 206. When the fatality rate (*fr*) is 0.1 (10%), that is, when 10% of infected individuals die, the total number of infected individuals (*TI*) reaches 663,369 on day 208. The total number of deceased individuals (*CDSUM*) was 66,337. When the fatality rate (*fr*) is 1.0 (100%), that is, when all infected individuals die, the total number of infected individuals (*TI*) reaches 507,403 on day 214.

The total number of deceased individuals (*CDSUM*) was 507,403. As described above, when deaths occur among infected individuals, according to the SIRD model, since the decrease in the number of "spreaders" is directly reflected in the calculations and the number of contacts between infected individuals and susceptible individuals is reduced, the total number of infected individuals (*CAP*) decreases with an increase in the fatality rate (*fr*), that is, with an increase in the ratio of the number of deaths (*DSUM* ratio) (Table 1, Figure 3).

2. In the modified SIRD model, as in the SIRD model, all infected individuals remain within the community, and deceased and recovered individuals are excluded from the community, but the current population of the community (*N*(*n*)) decreases by the number of deaths; that is, *N*(*n*) is given by the initial population of the community, *TN*(1), minus the cumulative number of deaths (*CDSUM*(*n*)); that is, *N*(*n*)=*TN*(1)-*CDSUM*(*n*). According to the modified SIRD model, if the fatality rate (*fr*) is 0, that is, if no deaths occur, as in the SIRD model, the total number (*TI*) of infected individuals reaches 674,892 on day 206. When the fatality rate (*fr*) is 0.1 (10%), that is, when 10% of infected individuals die, the total number of infected individuals reaches 683,987 on day 209. The total number of deaths (*CDSUM*) was 68,399. The current population (*N*) decreases from 1,000,000 to 931,601. The number of susceptible individuals (*RM*) was 316,013, and the total number of recovered individuals (*CR*) was 615,588; thus, the total was 931,601, which was equal to the current population (*N*). Additionally, the sum of the total number of recovered individuals (615,588) and the total number of deaths (68,399) becomes the total number of infected individuals (683,987). When the fatality rate (*fr*) is 1.0 (100%), that is, when all infected individuals die, the total number of infected individuals reaches 1,000,000 on day 386. The total number of deaths (*CDSUM*) reaches also 1,000,000 on day 396, meaning that everyone in the community will die. Although the occurrence of deaths in infected individuals reduces the number of 'spreaders', this occurrence of deaths decreases the current population of the community. And the decrease in the current population increases the number of contact rate between infected individuals and susceptible individuals, and it also increases the infection coefficient (the infectious capacity). As a result, the total number of infected individuals increases with increasing fatality rate, that is, with an increase in the ratio of the number of deaths, (Table 2, Figure 5). It is indicated that it is important to incorporate into calculations the fact that the community population decreases when deaths occur among infected individuals.

3. According to the flexible compartment model, the deceased individuals are excluded from the community, but the recovered individuals return from isolation to the community. Therefore, the current population of the community (*N*(*n*)) is the total population of the community minus the number of isolated individuals and the number of deaths plus the number of recovered individuals; that is, as explained previously, *N*(*n*)=*TN*(*n*-1)-(*CI*(*n*-1)+*CPI*(*n*-1) + *CDSUM*(*n*-1)) + (*CRI*(*n*-1)+*CRT*(*n*-1)), where *TN*(*n*) is the total population of the community. When *n* is 1, i.e., the first day of simulation, *N* (1) is *TN* (1). *CI*(*n*) is the cumulative number of isolated individuals due to a positive test, *CPI*(*n*) is the cumulative number of isolated individuals due to being symptomatic, and *DSUM*(*n*) is the cumulative number of deaths. (*CRI*(*n*)+*CRT*(*n*)) indicates the total cumulative number of the cumulative number (*CRI*(*n*)) of recovered individuals who returned from 'isolation due to positive results in the test' and the cumulative number (*CRT*(*n*)) of recovered individuals who returned from 'isolation due to symptom onset'.

When the symptomatic rate (*syr*) is set to 0, all infected individuals remain within the community and recovered individuals who have acquired immunity also stay in the community. Since there are no isolated individuals, there are also no recovered individuals who returned from isolation, and the current population of the community (*N*(*n*)) is inevitably equal to the total population of the community minus the cumulative number of deaths (*CDSUM*(*n*)); that is, *N*(n) = *TN*(n) – *CDSUM*(*n*). When the activity level (*AL*) of recovered individuals living in the community is set to 1, since the activity level of recovered individuals is the same as that of susceptible individuals, it is possible to more accurately represent the behavior of infected and recovered individuals and their infection status in the community. The flexible compartment model used in this article, which appropriately represents this situation, yields results different from those of the SIRD model and the modified SIRD model as follows:

According to the flexible compartment model, when the fatality rate (*fr*) is 0, that is, when deaths do not occur, the total number (*TI*) of infected individuals reaches 598,287 on day 178. When the fatality rate (*fr*) is 0.1 (10%), that is, when 10% of infected individuals die, the total number of infected individuals reaches 608,035 on day 181. The current population (*N*) decreases to 939,196. The total number of deaths (*CDSUM*) reached 60,804. The number of susceptible individuals (*RM*) is 391,965, and the total number of recovered individuals (*CR*) was 547,231; thus, the total was 939,196, which was equal to the current population (*N*). When the fatality rate (*fr*) is 1.0 (100%), that is, when all infected individuals die, the total number of infected individuals (*TI*) reaches 1,000,000 on day 386. The total number of deaths (*CDSUM*) also reached 1,000,000 on day 396, meaning that everyone in the community will die. According to the flexible compartment model, when deaths occur among infected individuals, since the number of recovered individuals (*R*) decreases, the 'contact rate reduction effect by recovered individuals' is reduced and the contact rate increases (see Eq. (1)), and the total number of infected individuals (*CAP*) increases (Figure 9). Furthermore, when deaths occur, since the current population of the community (*N*) decreases, the number of contacts increases (see Eq. (1)), and the infection coefficient (the infectious capacity) also increases (see Eq. (23), Figure 10). Therefore, when deaths occur, the total number of infected individuals (*CAP*) increases with an increase in the fatality rate (*fr*), that is, with an increase in the ratio of the number of deaths (*DSUM* ratio) (Table 3, Figure 7).

The SIRD model and the modified SIRD models tend to overestimate the number of infected individuals because they do not appropriately reflect the number of deaths and recovered individuals in the calculations of contact rate and the current population of the community (Figure 8). It is cautious that, in the SIRD models, when deaths occur among infected individuals, they provide false information that 'the total number of infected individuals is decreasing,' leading to misunderstandings about the dynamics of COVID-19 infection.

4. When the symptom rate (*syr*) of the flexible compartment model is set to 1.0, all infected individuals are isolated on the day after the end of the latent period, and recovered individuals,

excluding the deceased, return to the community on the day after the end of the recovery period (isolation period). The current population of the community ($N(n)$) is the total population (the initial population in this case) of the community minus the number of isolated individuals and the number of deaths but plus the number of recovered individuals; that is, as explained previously, $N(n)=TN(n\text{-}1)$ - $(CI(n\text{-}1)+CPI(n\text{-}1)+CDSUM(n\text{-}1))$ + $(CRI(n\text{-}1)+CRT(n\text{-}1))$, where $TN(n)$ is the total population of the community. When n is 1, i.e., the first day of simulation, $N(1)$ is $TN(1)$. $CI(n)$ is the cumulative number of isolated individuals due to a positive test, $CPI(n)$ is the cumulative number of isolated individuals due to being symptomatic, and ($DSUM$ (n) is the cumulative total number of deaths. $(CRI(n)+CRT(n))$ indicates the total cumulative number of the cumulative number ($CRI(n)$) of recovered individuals who returned from 'isolation due to positive results in the test' and the cumulative number ($CRT(n)$) of individuals who returned from 'isolation due to symptom onset'.

When the fatality rate (frI) is 0, that is, when no deaths occur among the isolated infected individuals, the total number (TI) of infected individuals reaches 141,787 on day 354. The total number of infected individuals, 141,787, was significantly less by 456,500 compared to 598,287 individuals when the symptom rate was set to 0.0, indicating that the symptom rate had a large effect on the occurrence of infection. When the fatality rate of isolated individuals (frI) is 0.1 (10%), that is, when 10% of isolated infected individuals die, the total number of infected individuals (CAP) reaches 154,181 on day 358. The total number of deaths ($CDSUM$) reached 15,418, and the total number of recovered individuals (CR) reached 138,764. The current population of the community (N) decreases to 984,582. When the fatality rate (frI) is 1.0 (100%), that is, when all infected individuals die, the total number of infected individuals reaches 1,000,000 on day 884. The total number of deaths ($CDSUM$) was also 1,000,000 on day 894, meaning that everyone in the community will die (Table 4, Figure 12). When deaths occur among infected individuals, the number of "spreaders" decreases; however, in a flexible compartment model, the number of recovered individuals also decreases, reducing the "contact rate reduction effect by recovered individuals," which increases the contact rate between infected individuals and susceptible individuals (see Eq. (1)), resulting in an increase in the total number of infected individuals (Figure 13).

According to the flexible compartment model, when the symptomatic rate is set to 1.0, that is, when all infected individuals are isolated, the total number of infected individuals is significantly lower than when the symptomatic rate is set to 0.0, meaning that all infected individuals remain in the community. However, when deaths occur among the isolated infected individuals, the total number of infected individuals increases significantly with an increase in the fatality rate, that is, with an increase in the ratio of the number of deaths (Figure 14).

5. According to the flexible compartment model, when the symptom rate is set to 0.5, half of the infected individuals are isolated because they become symptomatic, and recovered individuals, excluding the deceased, return to the community after the end of the recovery period (isolation period). The remaining half of the infected individuals are not isolated because they are asymptomatic and continue to live in the community, where the infection spreads. After the recovery period ends, except for the deceased, they become recovered individuals and continue to live in the community as before. The current population of the community ($N(n)$) is the total population of the community minus the number of isolated individuals and the number of deaths but plus the number of recovered individuals; that is, as explained previously, $N(n)=TN(n\text{-}1)\text{-}(CI(n\text{-}1)+CPI(n\text{-}1)+CDSUM(n\text{-}1))$ $+CRI(n\text{-}1)+CRT(n\text{-}1)$.

When both the fatality rate (frI) for the isolated infected individuals and the fatality rate (fr) for the infected individuals remaining in the community are 0, that is, when any death does not occur, the total number (TI) of infected individuals reaches 490,235 on day 200. The total number of infected individuals, 490,235, was significantly larger by 348,448 compared to 141,787 individuals when the symptomatic rate was set to 1.0, indicating that differences in symptomatic rates have a significant effect on the occurrence of infections. When both fatality rates are 0.1, that is, when 10% of both isolated infected individuals and infected individuals remaining in the community die, the total number (TI) of infected individuals reaches 501,109 on day 203. The total number of deaths ($CDSUM$) reached 50,111. When both fatality rates are 1.0, that is, when all of the isolated infected individuals and infected individuals remaining in the community die, the total number (TI) of infected individuals reaches 1,000,000 on day 460. The total number of deaths ($CDSUM$) also reached 1,000,000 on day 470. When both fatality rates are 1.0, that is, when all of the isolated infected individuals and infected individuals remaining in the community die, the total number (TI) of infected individuals reaches 1,000,000 on day 460. The total number of deaths ($CDSUM$) also reached 1,000,000 on day 470. As examined above, the total number of infected individuals increases significantly with an increase in the fatality rate, that is, with an increase in the ratio of the number of deaths of infected individuals (Table 5).

For the case where the fatality rate (fr) is 0, that is, for the case where no deaths occur among the infected individuals remaining in the community, when the fatality rate (frI) is 0, that is, when no deaths occur among the isolated infected individuals, the change in the number of infected individuals is the same as when both fr and frI are 0, and the total number (TI) of infected individuals becomes 490,235 on day 200. When frI is 0.1, that is, when 10% of isolated infected individuals die, the total number (TI) of infected individuals reaches 500,019 on day 201. The total number of deaths ($CDSUM$) reached 25,001. When frI is 1.0, that is, when all isolated infected individuals die, the total number (TI) of infected individuals reaches 618,153 on day 219. The total number of deaths ($CDSUM$) reached 309,077. As shown above, the total number of infected individuals increases with an increase in the fatality rate (frI), that is, with an increase in the ratio of the number of deaths of isolated infected individuals. However, the "increase ratio" is smaller than that when deaths occur for both isolated infected individuals and infected individuals remaining in the community (Table 6).

For the case where the fatality rate (frI) is 0, that is, for the case where no deaths occur among the isolated infected individuals, when the fatality rate (fr) is 0, that is, when no deaths occur among the infected individuals remaining in the community, the change in the number of infected individuals is the same as when both fr and frI are 0, and the total number (TI) of infected individuals becomes 490,235 on day 200. When fr is 0.1, that is, when 10% of infected individuals remaining in the

community die, the total number (*TI*) of infected individuals reaches 490,782 on day 202. The total number of deaths (*CDSUM*) reached 24,539. When *fr* is 1.0, that is, when all infected individuals remaining in the community die, the total number (*TI*) of infected individuals reaches 495,096 on day 226, and the total number of deaths (*CDSUM*) reaches 247,548. Although the 'increase ratio' is relatively smaller than that when deaths occur in both isolated infected individuals and those remaining in the community and when deaths occur only in isolated infected individuals, the total number of infected individuals (*TI*) increases with an increase in the fatality rate (*fr*), that is, with an increase in the ratio of the number of deaths among infected individuals. The reason the increase ratio is small is that 'half of the infected individuals are isolated, all of those isolated infected individuals recover, and return to the community', reducing the contact rate (Table 7).

When the symptomatic rate (isolation rate) is 0.5, the total number of infected individuals increases with an increase in the ratio of the number of deaths among the infected individuals, regardless of whether the infected individuals are isolated or remain in the community. However, the increase ratio in the total number of infected individuals due to an increase in fatality rate is greatest when deaths occur among both isolated infected individuals and those remaining in the community, next largest when deaths occur only among isolated infected individuals, and smallest when deaths occur only among those remaining in the community (Figure 15).

6. Whether reinfection occurs depends on the duration of infection-induced immunity (*dii*; the validity period of infection-induced immunity), and the duration of infection-induced immunity required for reinfection to occur varies depending on the potential infectious capacity of the coronavirus (*pfc*) and the symptomatic rate (*syr*). When the potential infectious capacity of coronavirus *(pfc*) is 1.0 and when the symptomatic rate is 1.0, that is, all infected individuals are isolated after the end of the latent period, if the duration of infection-induced immunity is set to 150 days, reinfection occurs regardless of whether death occurs, causing seven epidemics (seven outbreaks). The duration of each epidemic differed depending on whether death occurred (*frI*=0.1 in this article) or not (*frI*=0.0), but the difference was not very large. The duration of each epidemic tends to increase slightly as the epidemic progresses, regardless of whether deaths occur. However, the 'peak number of individuals infected a day' in each epidemic (the 'peak number of *AP*' in each epidemic)' and the 'total number of infected individuals in each epidemic ("*CAP*")' steadily decrease in both cases, regardless of whether deaths occurred. On the other hand, both the decreasing rates of the 'peak number of individuals infected a day in each epidemic' and the decreasing rate of the 'total number of infected individuals in each epidemic' differ between the cases where deaths do not occur and where deaths occur.

Specifically, the 'peak number of *AP*' and the 'total number of infected individuals ("*CAP*")' for each epidemic are greater when deaths occur, *frI*=0.1, than when deaths do not occur, *frI*=0.0, up to the third epidemic; these values become almost the same in the fourth epidemic and reverse from the fifth epidemic onward. That is, from the fifth wave onward, the 'peak number of *AP*' and the 'total number of infected individuals ("*CAP*")' for each epidemic became greater when *frI*=0.0 than when *frI*=0.1. At first glance, it may seem that the 'effect of an zincrease in infections due to the occurrence of deaths' has disappeared, but this occurs for the following reasons: when deaths do not occur (*frI*=0.0), all infected individuals recover and eventually get back to susceptible individuals (*RM*). On the other hand, when death occurs, the deceased individual is removed from the community, so the number of recovered individuals is reduced; as a result, the number of susceptible individuals (*RM*) decreases by the cumulative number of deaths (*CDSUM*). For example, in the fifth epidemic, the number of susceptible individuals for a fatality rate of 0.1 decreased to 947,133, which is 50,340 fewer than the 997,473 for a fatality rate of 0.0. As a result, when *frI* =0.1, both the 'peak of the number of infected individuals a day (*AP*)' and the 'total number of infected individuals ("*CAP*")' during the fifth epidemic decreased compared to those when *frI*=0.0 (Table 8, Figures 16-a, b and c).

Furthermore, when deaths occurred, since both the number of susceptible individuals and the population of the community are reduced with epidemic, the peak number of individuals infected a day during each epidemic was initially greater than that when no deaths occurred; however, this number rapidly decreased and subsequently reversed after the fifth epidemic (Figure 16-c), and the duration of infection became shorter than that when no deaths occurred. The duration of infection was 8,303 days when death occurred, for a fatality rate of 0.1 was considerably shorter than the 8,947 days when death did not occur. However, the final total number of infected individuals in the end of the infection certainly became greater when deaths occurred (the total number of infected individuals: 684,055) than when no deaths occurred (the total number of infected individuals: 681,884) (Figure 16-a and b).

Conclusion

Using a flexible compartment model specialized for COVID-19, the changes in the number of infected individuals were calculated in the event of death among the infected individuals during the infection process. Therefore, regardless of whether it was a direct cause of death, such as respiratory disease, or an indirect cause of death, such as worsening of underlying conditions or pre-existing diseases, "death of patients during infection", that is, "death of spreaders", was defined as "death of the infected individuals." Regardless of the cause of death, the "deaths of infected individuals" signify not only a decrease in the number of 'spreaders' but also a decrease in the number of recovered individuals and a decrease in the current population of the community.

In this article, the number of infected individuals refers to the number of 'confirmed infected individuals', and the number of 'deaths' also refers to the number of 'confirmed deaths.' Therefore, the "fatality rate" corresponds to both the "case fatality rate" (CFR), the fatality rate among confirmed infected individuals, and the "infection fatality rate" (IFR), the fatality rate among the total infected individuals.

Furthermore, in this article, two fatality rates were used. One is the fatality rate of isolated individuals, '*frI*(*n*)', and the other is the fatality rate of asymptomatic infected individuals, '*fr*(*n*)'. It should be noted that the 'fatality rate of asymptomatic infected individuals' was, in practice, used for calculations as 'the fatality rate of infected individuals living in the community without isolation,' regardless of whether they had symptoms or were asymptomatic.

In this article, all the independent variables, including the infectious capacity of coronavirus, symptomatic rate, and fatality rate, as well as the latent period and recovery periods, are used as "average values." For example, if deaths occur, infected individuals may die before the end of the recovery period. In the model of this article, the average day of death was set as the "midpoint day between the end of the latent period and the end of the recovery period".

1. According to the SIRD model, all infected individuals stay in the community, and both deceased and recovered individuals are excluded from the community; however, the population of the community remains constant: 'susceptible + infected + recovered + deaths'. When deaths occur among infected individuals, since the SIRD model directly reflects the decrease in the number of "spreaders," the total number of infected individuals decreases with an increase in the fatality rate, that is, with an increase in the ratio of the number of deaths.

2. In the modified SIRD model, as in the SIRD model, all infected individuals remain within the community and deceased and recovered individuals are removed from the community. However, the current population of the community decreases by the number of deaths; that is, the current population is equal to the initial population minus the cumulative number of deaths. The occurrence of deaths in infected individuals decreases the number of 'spreaders'. However, since the occurrence of deaths decreases the current population of the community, the number of contacts between infected and susceptible individuals increases, and the infection coefficient (the infectious capacity) also increases. As a result, the total number of infected individuals increases with an increase in the fatality rate, that is, with an increase in the ratio of the number of deaths. This indicates that it is important to incorporate into calculations the fact that the current population of the community decreases when deaths occur among infected individuals.

3. In a flexible compartment model, by setting the symptomatic rate to 0, all infected individuals remain within the community, resulting in the same state as in the SIRD model. However, unlike in the SIRD model and the modified SIRD model, the current population of the community is determined by subtracting the number of infected individuals kept in isolation and the number of deaths from the initial population while adding the number of recovered individuals. According to the flexible compartment model, when deaths occur among infected individuals, since the number of recovered individuals decreases, the 'contact rate reduction effect by recovered individuals' is reduced, and the number of contacts between infected and susceptible individuals increases. Furthermore, when deaths occur, since the current population of the community decreases, the number of contacts increases, and the infection coefficient (the infectious capacity) also increases. Therefore, when deaths occur, the total number of infected individuals increases with an increase in the fatality rate, that is, with an increase in the ratio of the number of deaths.

In the SIRD models, because they do not appropriately reflect the number of deaths and recovered individuals in the calculations of contact rate and the current population of the community, when deaths occur among infected individuals, they provide false information that "the total number of infected individuals is decreasing," leading to misunderstandings about the dynamics of COVID-19 infection. Therefore, caution is necessary when using the SIRD models.

4. According to the flexible compartment model, when the symptomatic rate is set to 1.0, that is, when all infected individuals are isolated, the total number of infected individuals is significantly lower than when the symptomatic rate is set to 0.0, meaning that all infected individuals remain in the community. However, when deaths occur among isolated infected individuals, the total number of infected individuals increases significantly with an increase in the fatality rate, that is, with an increase in the ratio of the number of deaths. This fact, conversely, indicates that when an epidemic occurs, caring for infected individuals by isolating them, providing care, aiding in their recovery, and returning them to the community are critical measures for controlling the infection.

5. According to the flexible compartment model, when the symptom rate is set to 0.5, half of the infected individuals are isolated because they develop symptoms, and the recovered individuals, excluding the deceased individuals, return to the community after the end of the recovery period (isolation period). The remaining half of the infected individuals are not isolated because they are asymptomatic, continue to spread the infection in the community, and, excluding the deceased, become recovered individuals after the end of the recovery period.

When the symptomatic rate (isolation rate) is 0.5, the total number of infected individuals increases with increasing fatality rate. Namely, the total number of infected individuals increases with an increase in the ratio of the number of deaths among the infected individuals, regardless of whether the infected individuals are isolated or remain in the community. However, the increase ratio in the total number of infected individuals due to an increase in fatality rate is greatest when deaths occur among both isolated infected individuals and those remaining in the community, followed by deaths occurring only among isolated infected individuals and, finally, those occurring only among those remaining in the community.

In addition, the results of the calculation show that "when the symptomatic rate increases, that is, when the number of isolated individuals increases, the number of infected individuals is reduced." This indicates that 'isolating more infected individuals, reducing deaths among those isolated, and returning more recovered individuals to the community' are effective measures for controlling the spread of infection.

6. Whether reinfection occurs depends on the duration of infection-induced immunity (the validity period of infection-induced immunity), and the duration of infection-induced immunity required for reinfection to occur varies depending on the symptomatic rate and the potential infectious capacity of the virus. When the symptomatic rate is 1.0 and the potential infectious capacity of coronavirus is also 1.0, if the duration of infection-induced immunity is 150 days, reinfection occurs accompanying 7 epidemics (outbreaks) regardless of whether deaths occur. The duration of each epidemic differed depending on whether death occurred (frI=0.1 in this article) or not (frI=0.0), but the difference was not very large. The duration of each epidemic tends to increase slightly as the epidemic progresses, regardless of whether deaths occur. However, the 'peak number of individuals infected a day' in each epidemic (the 'peak number of *AP*' in each epidemic)' and the 'total number of infected individuals in each epidemic ("*CA*P")' steadily decreased in both cases, regardless of whether deaths occurred. On the other hand, both the decreasing rates of the

'peak number of individuals infected a day in each epidemic' and the decreasing rate of the 'total number of infected individuals in each epidemic' differ between the cases where deaths do not occur and where deaths occur.

When deaths occur, since both the number of susceptible individuals and the current population of the community decrease as the epidemic progresses, the peak number of individuals infected a day during each epidemic initially becomes greater than if no deaths occur; however, it rapidly decreases and eventually reverses, and the duration of infection is shorter than when no deaths occur. However, the final total number of infected individuals at the end of the infection becomes greater when deaths occur than when deaths do not occur.

The results of all the cases simulated by the flexible compartment model showed that "when deaths occur, the number of infected individuals increases." Since a certain proportion of infected individuals die, first, it is essential to implement measures to reduce the number of infected individuals, such as wearing masks, isolating through PCR tests, and getting vaccinated. And the results of the simulation in this article indicate that "isolating more infected individuals, reducing the deaths of those isolated infected individuals, recovering more isolated infected individuals and returning them to the community" are effective measures for controlling the spread of infection.

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