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Measures to prevent and control the spread of novel coronavirus disease (COVID-19) infection in tourism locations

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ABSTRACT
This study reproduces the infection process of 2019 novel coronavirus diseases (COVID-19) in an agent-based model and compares the effects of multiple infection prevention and control measures for a tourism location. In this model, 3200 virtual resident agents live in nine areas where they commute to employment locations or schools and visit stores. This model simulates a spreading infection process, brought by a continuous influx of tourists. The experiments' results showed that an individual infection prevention measure alone or partially combined measures are insufficient. On the other hand, we confirmed that regular PCR testing for tourism business employees and an active epidemiological investigation are effective.

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1. Introduction

On July 22, 2020, as Japan had its second wave of COVID-19 infections, the 'Go To Travel' campaign was launched with the aim of economic stimulation in tourism areas by promoting consumption [1]. On the other hand, the government decided to limit travel to the Tokyo area and travel by Tokyo area residents since the number of positive COVID-19 test results increased steadily since the previous month. In some tourist destinations such as Okinawa, the spread of infection worsened due to increased new positive results in major cities, unknown contact history, and the percentage of positive tests. On October 1, given the governmental update that the situation was under control, the exclusionary measures about the Tokyo area were abolished [2], and the tourism promotion measures established by the directive to 'make Japan better through travel' were executed in full, even amid unease and mistrust. To spread and embed the ideals of travel based on the new normal while living with COVID-19, the Go To Travel project guidelines include compliance requirements for safe and secure travel such as temperature checks every morning, the use of contact tracing apps, avoiding the three Cs, staying confined when feverish, and taking definite infection pre-prevention measures when travelling in groups. However, while the effectiveness of these countermeasures has not been demonstrated, as a requirement for participation, travellers were asked to agree to comply with the new travel etiquette. Also, businesses were required to implement COVID-19 infection prevention countermeasures.

Elsewhere, preliminary calculations were announced stating that the GDP had decreased by 27.8% in the April–June period because of COVID-19 and that economic losses were expected to reach 13.3 trillion yen [3]. The impact on the tourism industry, in particular, is far-reaching, including not only travel agencies and accommodation businesses but also land, sea, and air transport, the restaurant industry, and consumer goods businesses. They are crucial to the economies of many regions. For example, a preliminary calculation of economic losses in Okinawa due to the reduction in tourists was 186.7 billion yen for the February–May period [4] and total domestic travel and tourism expenditure in 2019, including inbound tourism, was 27.9 trillion yen [5]. There were serious concerns that the 'evaporation' of the tourism demand supporting regional economies would cause critical disruption. Therefore, this study designs a model of the spread of COVID-19 infection in tourism locations and compares the effects of hypothetical prevention and control measures to find feasible, effective, astute infection prevention and control measures considering the effects both on those directly involved in the target regions and on others. Infection prevention and control measures are be categorized into two types of approaches: a top-down approach and a bottom-up approach. The top-down approach refers to strong government restrictions, such as declaring a state of emergency and closing shops and restaurants. On the other hand, the bottom-up approach refers to voluntary personal behaviour, such as avoiding the three Cs

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(closed spaces, crowded places, and close-contact settings), face masking, and self-restraint of movement. The purpose of this study is to examine a combination of infection prevention and control measures that enable the sustainable economic activities of the entire region.

1.1. COVID-19 simulations

Even with the negative impacts of COVID-19 infections around the world, we have acquired greater expertise. Accordingly, several researchers are working on modeling social systems that include non-linear interaction to create simulations for policy-making support toward the prediction of infection expansion in the future, which is almost impossible by intuition alone, to resolve the situation. The SIR (Susceptible, Infectious, Recovered) model, a mathematical epidemiology model based on classic ordinary differential equations, has also been applied to COVID-19 epidemiological dynamics. In addition to estimating the short-term infection peak period in Italy, the number of those infected, and the final number of fatalities, based on the analysis of the initial infection expansion in China, Italy, and France, Fanelli et al. demonstrated that drastic behavioural regulation could control the peak [6]. Dehning et al., by combining the SIR model with Bayesian inference, evaluated the efficacy of three intervention measures aimed at ensuring social distancing by the German government and demonstrated that the manifestation of the efficacy of intervention operates on a 2-week delay. They said drastic behavioural control measures must be taken to control the expansion of infection, and that the cancellation of these interventions must be implemented carefully because of the delayed manifestation of their effects [7]. Further, an approach based on the SEIR model is being used with attention to the infection of others before the onset of symptoms or when asymptomatic, which is characteristic of COVID-19, leading to 'Exposed' infected people. Kissler et al., based on an analysis of seasonal effects due to immune cross-response and immunological response with other types of coronavirus, demonstrated that intermittent social distancing-ensuring measures will be required over several years to maintain the health system in the United States and estimate that repeated outbreaks will occur, mainly in fall and winter [8]. Hellewell et al., based on a probabilistic transmission model with the parameters set for COVID-19, demonstrated that it can be resolved within 3 months if sufficient tracking and isolation of those in contact with infected people are implemented [9]. Based on population data by age in Ontario, Canada, of non-medical intervention scenarios, Tuite et al. estimated a shortage of ICU beds if basic physical distancing is not ensured or if there is no combination of middling physical distancing and reinforced case finding and demonstrated that ensuring physical distancing may maintain the capacity of healthcare systems and reduce economic losses and the psychological burden on citizens [10].

1.2. COVID-19 agent-based simulations

Agent-based models excel at the manifestation of effects through micro-level behavioural changes among individual citizens as specific intervention measures against infection, as well as at operability based on intervention scenario findings. Therefore, they are used with existing infectious diseases, such as smallpox [11–13], measles [14,15], Zika fever [16], Ebola haemorrhagic fever [16,17], and rubella [18]. As for the proposed COVID-19 simulations, most are based on macro-scale mathematical models including the studies discussed in the previous section, but there are also some interesting agent-based models. Ferguson et al. reported that non-medical intervention such as wider social distancing, home isolation, and home quarantine throughout the UK and the United States may mitigate the spread of the infection to some degree, but as long as there is no prevention system such as a vaccine or antiviral drug, pressure on medical resources is unavoidable, and large numbers of fatalities are likely [19]. Based on this report, the UK government shifted immediately from its initial mass immunization strategy to strict intervention measures to ensure social distancing. Silva et al. simulated not only the epidemiological dynamics but also an estimation of the economic effect of various intervention scenarios with regard to ensuring social distancing and demonstrated that where a lockdown is unfeasible because of the scale of economic impact, a combination of the use of face masks and partial isolation is more realistic [20]. Aleta et al. constructed an agent-based model based on census research and movement data in the greater Boston area and demonstrated that by means of testing, contact tracing, and home quarantine after a period of strict social distancing, it was possible to resume economic activity while protecting the health system [21].

1.3. Summary of related studies and positioning of this study

These studies demonstrate that an agent-based model effectively estimates pandemics but does not sufficiently verify the effects of non-medical interventions. This study focuses on the heterogeneity of residents' daily lives and their close relations to these interventions when a vaccine or antiviral drug is unavailable. Further, there are no spatial or temporal estimates of regional characteristics with regard to countermeasures and their effects on parts of tourism locations, for instance, that receive intermittent influxes of people from other

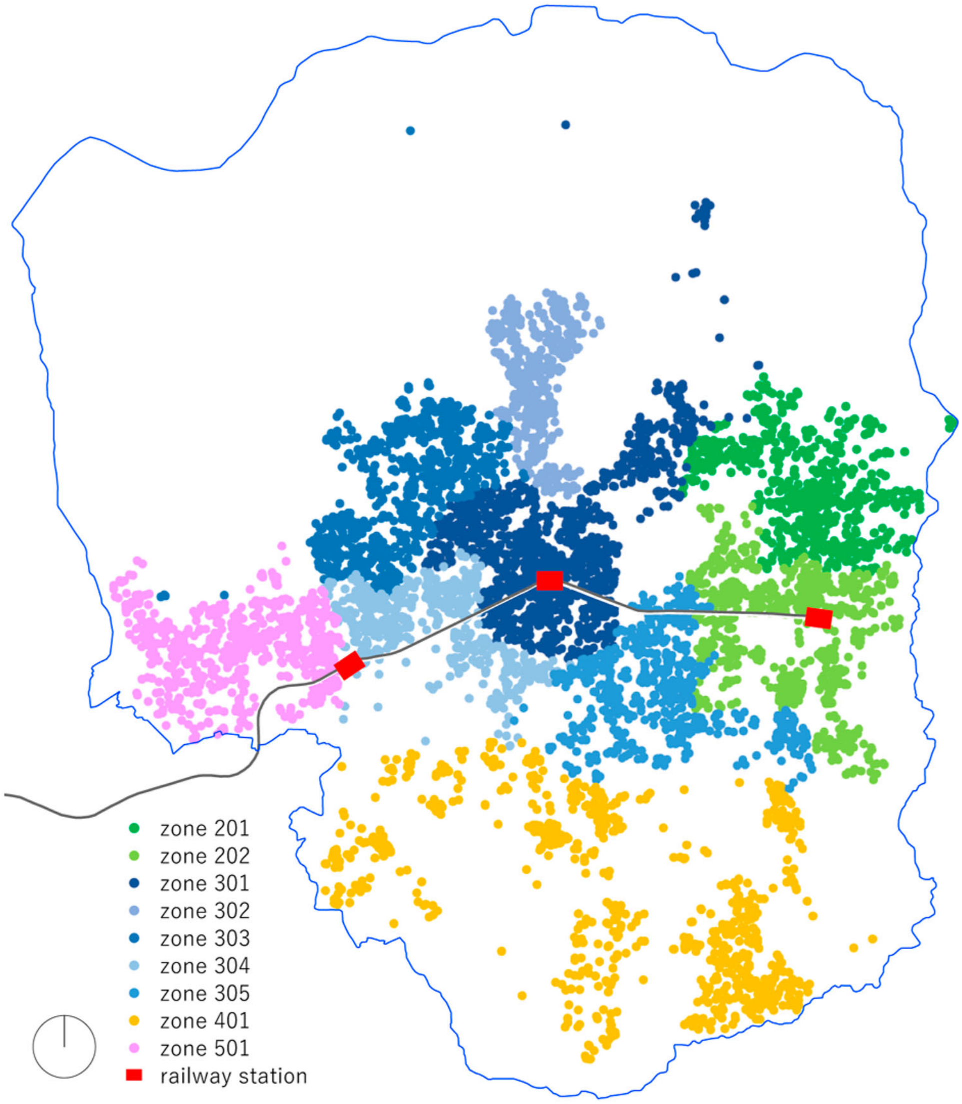

Figure 1. Population distribution of the town.

regions. Therefore, this study explores feasible, effective non-medical infection prevention and control measures using a COVID-19 agent-based model with the assumption of specific tourism locations.

2. COVID-19 infection model for tourism locations

This model is constructed for a tourism location in Nagano Prefecture as an expansion of existing infectious disease studies in which validity evaluations have been conducted for the transition of infection [17,18,22]. The model uses restored population data created with the household composition restoration method [23], a method of restoring population data so that it conforms to various published statistics (e.g. national census, demographics, business/industry statistics, etc.), which is optimized using SA with the errors in the recreated data (restored data) collation after calculation as the objective function. This restored population data includes the longitude and latitude of the location of the household and its members' gender, age, employment status, type of industry, the scale of business, etc. Using these data, Figure 1 shows the population distribution of the target town. With attention to place names, terrain, road connections, school district divisions, etc., the town is divided into nine zones, as shown in the figure. The central area is traversed by a local railroad, with residential areas distributed next to the line along with scattered holiday home areas. The town has three local railway stations, with the areas from the left facing these stations – the West Station, Central Station, and East Station. Public facilities such as government buildings, schools, and hospitals are concentrated around the Central and East Station areas. The East Station area, where the local railroad meets the main line railroad, has several promenades, shopping districts, lodging facilities, shopping malls, etc., which draw in many tourists.

The total population based on the restored population data is approximately 17,000 people, but for ease of calculation, it was rounded down to approximately 1/5 in the model. However, the ratios of household composition, number of households, population per

Table 1. Population composition.

	Actual town	Model
Population	16,911	3200
Number of households	7561	1459
Average household size	2.2	2.2
0–29 years old (young)	23.1%	23.4%
29–64 years old (adults)	47.0%	48.2%
65- years old (elderly)	29.9%	28.3%
Average age	48.3	–

Table 2. Model household composition.

Househould composition	Households	Population
Single (adult)	250	250
Single (elderly)	200	200
Couple (adults)	125	250
Couple (elderly)	300	600
Couple + one child	200	600
Couple + two children	175	700
One parent + one child	125	250
Couple + parents	5	20
Couple + one parent	30	90
Couple + one child + parents	8	40
Couple + two children + parents	10	60
Couple + one child + one parent	15	60
Couple + two children + one parent	16	80
Total	1,459	3,200

Table 3. Employment locations of workers.

Employment locations	Ratio
Hospitality industry	**25%**
Local shop 6	
Tourist spot 3	
Shopping mall	
Hotel 3	
Nightspot	
Education	**2%**
Childcare facility 4	
Elementary school 3	
Junior high school	
Senior high school 2 (1 in the town and 1 outside	
Hospital	**3%**
Other employment locations (in the town)	**35%**
Other employment locations (outside town)	**35%**

zone, etc. were set according to the actual population composition Table 1

Table 2 shows the model household composition.

2.1. *Behaviour of resident agents*

Resident agents in the model who commuted to work or school were set based on restored population data, municipal public information regarding public facilities, tourism guides, etc. 69% of young people – that is, 19% of the total population (520 agents) – attended childcare facilities or school. There were four childcare facilities, three elementary schools, junior high school in the town, as well as two senior high schools either in the town or outside the town. 70% of the remaining young people, 80% of adults, and 30% of the elderly – that is, 52% of the total population – were workers. This corresponds to a 51.9% total employment ratio in the restored population data. Table 3 shows the employment locations of workers.

The area is a popular tourist location. The ratio of employees at wholesale or retail businesses, accommodation or food service businesses, daily life-related services, and entertainment businesses was 46%, almost half of the total. Reflecting this, the ratio of workers in actual customer-facing roles was set at 25%, just over half. These employees in the hospitality industry are considered to have contact with tourists, the main topic of this study.

In the hospitality industry, local shops and tourist spots are established near West, Central, and East stations in the model area, with their employees set as residents of nearby areas. A shopping mall, accommodation facilities, and nightspots were established near East Station, with their employees set as living across town. Figure 2 shows the household and facility distribution in the model space.

Some of the resident agents other than workers at local shops go shopping at local stores adjacent to their residential zones after work or school. After shopping, all resident agents other than hospital inpatients go home. Figure 3 shows the flowchart of this series of behaviour for resident agents in the model. The simulation model defines the completion of this series of behaviour for all resident agents as one day. Resident agents repeat this series of behaviour throughout the run of the simulation.

2.2. *Process of infection and symptom*

In each round of simulations, infection is modeled on local interaction among resident agents. Resident agents are activated sequentially in random order, and they move explicitly spatially on the model according to the flowchart of Figure 3. In the rounds surrounded by the double line in Figure 3, in the case of contact with other infections resident agents on the model plane, the contact ratio cr is generated probabilistically because of interaction, with infection occurring in line with the transmission ratio tr. The infection ratio ir, the probability of the occurrence of infection, is defined as follows.

$$ir = cr * tr \tag{1}$$

This infection ratio ir is applied to every contact between active agents in their daily life shown in Figure 3: several times in one day. Based on reports of detailed analyses of the infection prevalence of COVID-19 [24,25], the following process of the progress of symptoms is defined. The incubation period is 5 days following infection, but the person can infect others by the third day even during this period. On the sixth day, when the incubation period has ended, symptoms such as fever, coughing, and diarrhoea occur in most infected people. After the fever, the basic scenario includes a 50% probability of home isolation after visiting a doctor. This probability of visiting a doctor is set

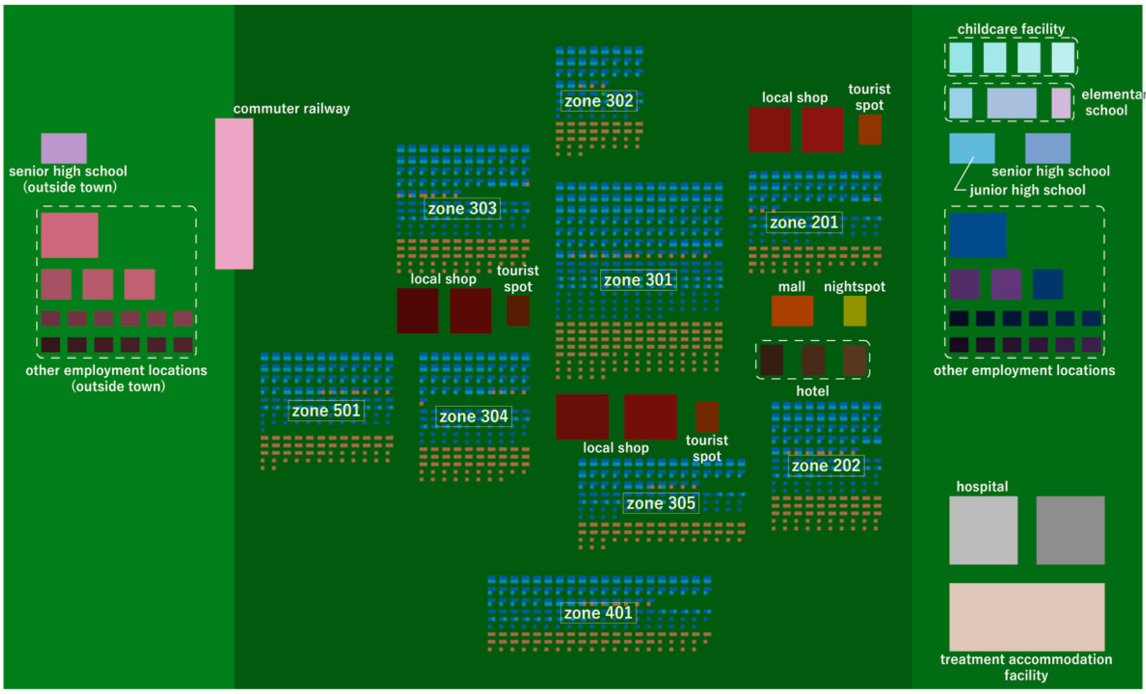

Figure 2. Household and facility distribution.

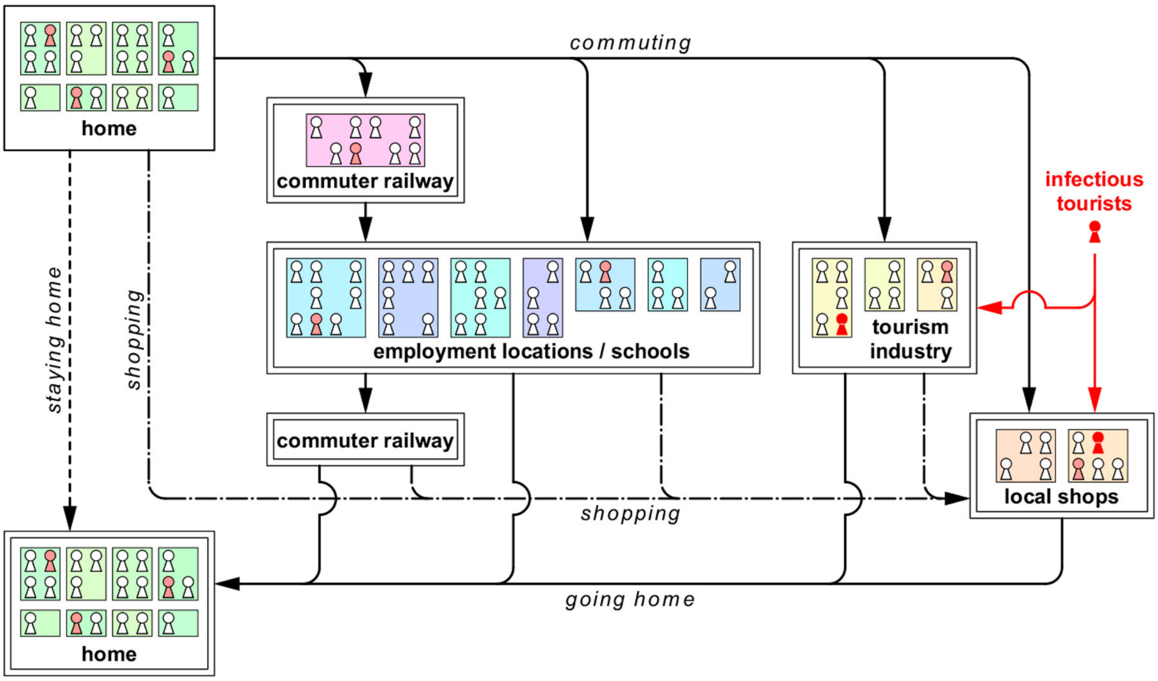

Figure 3. Flowchart of the daily life of resident agents.

to 50% because the number of symptomatic infected people is drastically lower than the actual number of infected people including asymptomatic carriers. The remaining 50% of infected people are either essentially asymptomatic or have minor symptoms, so they continue to go to work or school while self-medicating with febrifuges, etc. After the symptoms have continued for 4 days or more, infected people see a doctor and undergo a PCR test. The results are confirmed the following day, leading to hospitalization if the results are positive. Further, 20 days after infection, 20% of infected people become seriously ill and are hospitalized even without having seen a doctor in advance. Also, by 41 days after infection of those hospitalized with serious symptoms, fatalities comprise 0.06% of young people, 0.21% of adults, and 1.79% of the elderly. These fatalities rate is just applied to infected patients. The mildly ill recover by 27 days after infection and the surviving seriously ill by 49 days after infection, achieving temporary immunity. The simulation stops after all infected agents have recovered or 365 days (one year) have passed.

2.3. Validation of simulation models

In an Ebola haemorrhagic fever model [17], a rubella model [18], and a COVID-19 model [22] in existing infectious disease studies, validity evaluations of them have been conducted for the transition of infection. The basic suburban model for validation is an expansion of these models by reflecting new findings related to the infection process of COVID-19 as parameters.

This model is a relatively abstract middle-range model excluding regional characteristics and consists of households, workplaces, schools, public transport facilities, shops, and hospitals. 1120 resident agents from 400 households repeat commuting and shopping, reflecting the actual data such as enrolment rate and employment rate by age group. The daily behaviour of these resident agents follows the settings same as the tourism location model described in Subsection 2.1. At the start of the simulation, only one resident agent is infected. In each round of the simulation, infection occurs probabilistically when resident agents contact with each other on the model plane. The infection and symptom process follows the settings same as the tourism location model described in Subsection 2.2. That is, the basic suburban model is essentially equivalent to the tourism location model. Therefore, the validity of the model is confirmed employing a comparison between the actual transition in the number of newly confirmed positive cases during the early period of infection expansion and the simulation outcomes of the basic suburban model.

The specifications of this simulation were to abstract infection situations in a small number of infected people and small communities around them. Therefore, it was not oriented to compare the simulation population or number of positive cases with the actual absolute population or number of positive cases in a specific location. Rather, it was oriented towards comparisons in relative indicators such as the ratio of increase of positive cases, effective reproduction number, and timing of key events in an epidemic. Therefore, in the comparison, three quantitative criteria are used: ratio of increase of positive cases, days to the peak in the number of new cases, and effective reproduction number, during the early period of infection expansion.

The validity of the models is also verified by means of a comparison between a rise of the actual infection in the target area and the outcomes of the simulated tourism location model.

2.3.1. Ratio of increase of positive cases

Figure 4 shows the transition in the number of newly confirmed positive cases and the ratio of increase of positive cases in Tokyo between mid-February and April 3, 2020, based on official documents [26]. The number of positive cases as reported in mid-February remained at around 10 people per day for some time. However, from the end of March onward, the situation changed completely: 41 newly positive cases were reported on March 25 and 91 on April 2. This sudden increase among newly positive cases consistently exceeded 1.1. That is, a rate of increase regularly exceeding 1.0 signifies an accelerating rise in the number of infected people, so close attention is required to the changes in this value.

Figure 5 shows the transition of infection in the basic suburban model in which the active epidemiological investigation is conducted in Tokyo(Scenario B2) (median implementation of 100 times). In this scenario, there is no lockdown, and only an active epidemiological investigation is conducted.

The approximate linear function of the rate of increase of infected people in the first phase of increased infection was $y = -0.001x + 1.173$ in Tokyo, similar to Scenario B2 ($y = -0.0017x + 1.177$).

2.3.2. Days to the peak in the number of new cases

Also, the trend in the transition in infection is almost the same as that recorded in Wuhan, China [24]. After the first infected people were confirmed in Wuhan, approximately 60 days passed before the number of newly confirmed positive cases peaked. In Scenario B2 transition, as well, the first confirmation of positive cases was approximately 20 days after the first detection of infection. That means the simulation start date and approximately 60 days were needed to reach the peak in the number of new cases.

2.3.3. Effective reproduction number

Further, the effective reproduction number was around 3.0 in the initial period of increased infection, decreasing as the number of cases increased and dropping below 1.0 after about 90 days. The basic reproduction number R0 reported by WHO in the Wuhan infection was 2–2.5 up to January 23, when the authorities had not intervened [25], almost the same as the estimated value of 2–2.3 in the first phase of increased infection up to the peak number of newly confirmed positive cases in Scenario B2. Likewise, this is roughly similar to the domestic effective reproduction number reported by Novel Coronavirus Expert Meeting [27,28].

2.3.4. Discussion on validation

This research attempts to estimate the spread of infection under the limited condition that infection in tourism locations, including the target tourism location, had not been analysed in detail during the early period of infection expansion. At the time, the factors of the spread of infection in Tokyo were almost equivalent to those in the target tourism location, such as the nature of the pathogen, the progression of symptoms, the patterns of residents' behaviour, and the adopted infection prevention measures. In terms of the ratio

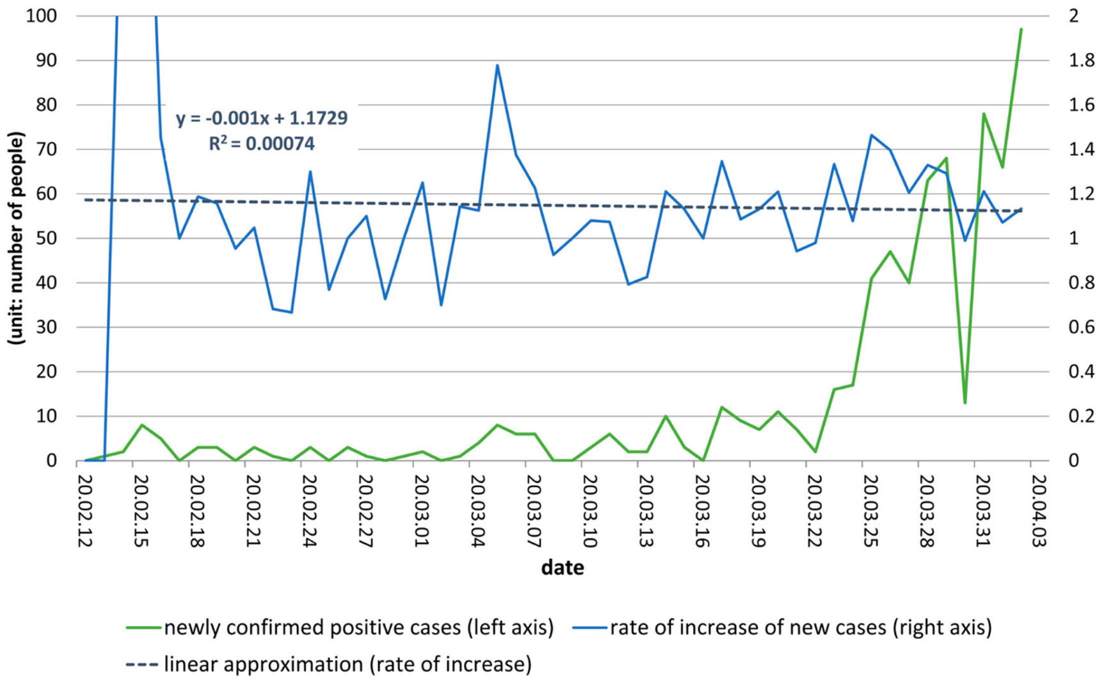

Figure 4. Transition in the number of newly confirmed positive cases and rate of increase of positive cases (Tokyo).

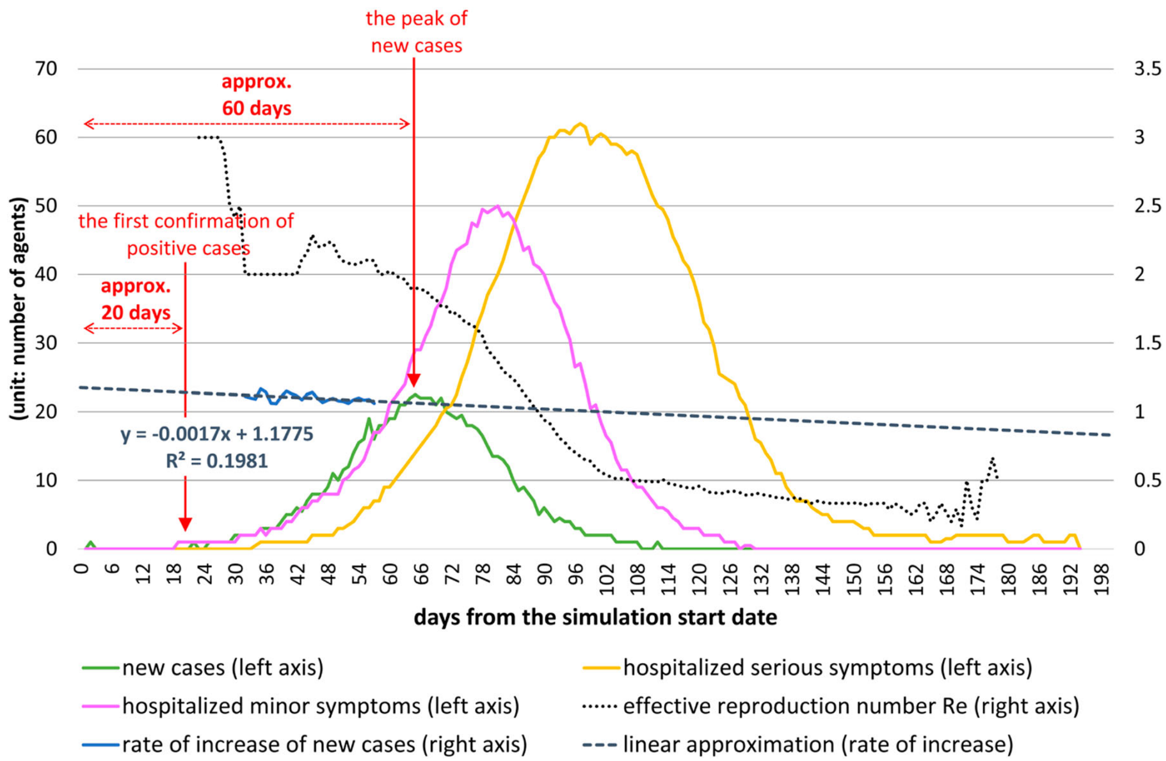

Figure 5. Scenario B2: Transition in the number of newly infected cases and hospitalized cases with serious/minor symptoms per day, effective reproduction number, and correlated rate of increase of new cases according to active epidemiological investigations.

of increase of positive cases and the effective reproduction number, the patterns of the basic suburban model corresponded to the data of Tokyo. Because the tourism location model is essentially equivalent to the basic suburban model, this correspondence is an important suggestion of the validity of the tourism location model. In addition, at the time, the peak in the number of new cases was confirmed only in Wuhan. Therefore, in terms of the peak in the number of new cases, the confirmation of the correspondence between the pattern of the basic suburban model and the data of Wuhan was the available and effective validation method. Thus, although under the limited condition, we confirmed that the emergent patterns not directly defined as parameters in the model settings quantitatively corresponded to the multiple observed patterns that characterize the modelling target systems. This means the validity of this simulation model based on the validation method of pattern-oriented models [29].

In addition, from the viewpoint of pattern-oriented scenario analysis, the following two items also qualitatively corresponded (see Section 4).

- The pattern of the increase in total cases brought about by a continuous influx of tourists in the outcomes of the simulated tourism location model
- The increase of the number of newly confirmed positive cases as the increase of the estimated number of influxes of infected people in Nagano prefecture, which includes the target tourism location

This correspondence also supports the validity of this simulation model.

3. Estimating effects of infection prevention and control measures

For this model, simulation scenarios for infection prevention and control measures for the entire region were set, including the hospitality industries that infected tourists may use. Table 4 shows the list of detailed settings.

In Scenario B0, tourists are not accepted by the hospitality industry overall, and there is no influx of infections, but one resident is infected at the initial point. In Scenario B1, tourists are accepted by the hospitality industry overall, and one infected person per week enters. In Scenario S1, contact with tourists by hospitality industry workers is reduced by 50%; in Scenario S2, nightlife districts close down voluntarily; in Scenario S3, contact with tourists by hospitality industry workers is reduced by 25%; and in Scenario S4, contact with tourists by hospitality industry workers is reduced by 25%, nightlife districts close voluntarily, and those testing positive are isolated at a treatment accommodation facility. In scenarios S5–S10, contact between hospitality industry workers and tourists is reduced by 25%, workers undergo regular PCR testing, and those testing positive are isolated at a treatment accommodation facility. In scenarios S11–S14, contact between hospitality industry workers and tourists is reduced by 25%, forward tracking (once or twice) of persons in close contact and PCR tests are implemented, and those testing positive are isolated at a treatment accommodation facility. Here the first forward tracking of persons in close contact to prevent further infection expansion is implemented by tracking tests via the contact app COCOA [30], etc. for persons in post-infection close contact with people who have tested positive for infection. The second forward tracking involves further tracking tests for persons in post-infection close contact with people who have tested positive in the forward tracking testing. The tracking ratio was defined as

Table 4. Simulation scenarios for infection prevention and control measures.

scenario ID	tourists	influx of infections	hotels	nightspots	tourist spots	mall	isolation	testing system	testing/tracking ratio
B0	Not accepted	One infected resident	–	–	–	–	–	–	
B1	Accepted	One per week	100%	100%	100%	100%	–	–	
S1	Accepted	One per week	50%	50%	50%	50%	–	–	
S2	Accepted	One per week	100%	close	100%	100%	–	–	
S3	Accepted	One per week	25%	25%	25%	25%	–	–	–
S4	Accepted	One per week	25%	close	25%	25%	Yes	–	–
S5	Accepted	One per week	25%	25%	25%	25%	Yes	Hospitality industry workers every 2 weeks	50%
S6	Accepted	One per week	25%	25%	25%	25%	Yes	Hospitality industry workers every 2 weeks	75%
S7	Accepted	One per week	25%	25%	25%	25%	Yes	Hospitality industry workers every 2 weeks	100%
S8	Accepted	One per week	25%	25%	25%	25%	Yes	Hospitality industry workers every 5 days	50%
S9	Accepted	One per week	25%	25%	25%	25%	Yes	Hospitality industry workers every 5 days	75%
S10	Accepted	One per week	25%	25%	25%	25%	Yes	Hospitality industry workers every 5 days	100%
S11	Accepted	One per week	25%	25%	25%	25%	Yes	Forward tracking (once)	50%
S12	Accepted	One per week	25%	25%	25%	25%	Yes	Forward tracking (once)	80%
S13	Accepted	One per week	25%	25%	25%	25%	Yes	Forward tracking (twice)	50%
S14	Accepted	One per week	25%	25%	25%	25%	Yes	Forward tracking (twice)	80%
S15	Accepted	One per week	25%	25%	25%	25%	Yes	Forward (twice) and backtracking	50%
S16	Accepted	One per week	25%	25%	25%	25%	Yes	Forward (twice) and backtracking	80%

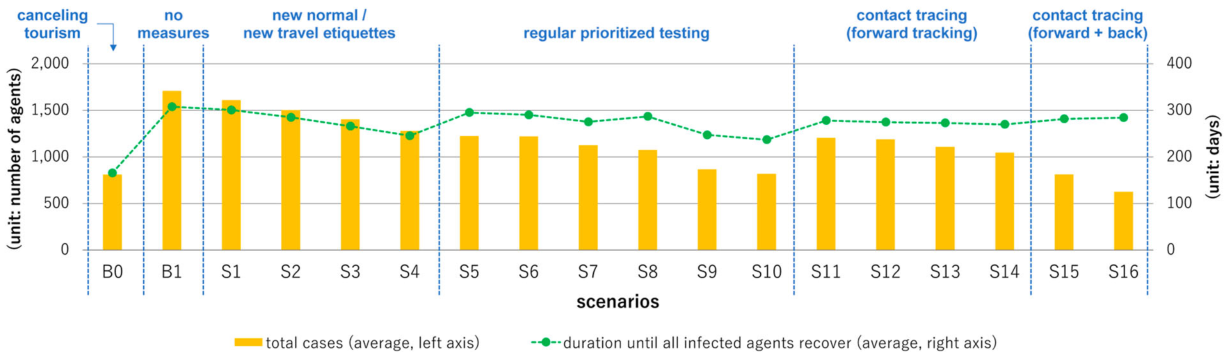

Figure 6. Comparison of the effectiveness of preventive measures on total cases and duration until all infected agents recover.

the probability that the public health sector finds persons in close contact and the infection source. PCR tests were implemented to find persons in close contact and the infection source, and those who were confirmed as positive are isolated. In scenarios S15 and S16, contact between hospitality industry workers and tourists is reduced by 25%, forward and backtracking of persons in close contact and PCR tests are implemented, and those testing positive are isolated at a treatment accommodation facility. Here, backtracking of persons in close contact is tracking tests for persons in pre-infection close contact with people testing positive for infection, to identify the source of infection.

4. Experiment results

Each simulation scenario was implemented 100 times. The results on the indexes of total cases and duration until all infected agents recover are shown in Figure 6. The results on the indexes of fatalities and peak patients are shown in Figure 7.

In Figure 6, the duration until all infected agents recover is not so different for any infection prevention and control scenario. It is because of the simulation setting as infected tourists inflow continuously. For the same reason, the number of total cases is relatively high in all the scenarios. As long as these cases occur sporadically, they would not significantly impact on the medical resources in the region. In Figure 7, each peak value does not mean the number of the new cases occurred on that day. Instead, these value refers to the cumulative values of patients at that day; therefore, they means the required number of medical resources, e.g. beds and ventilators. Therefore, the infection prevention and control measures were evaluated by the average of the peak number of people hospitalized with serious symptoms, which is the particularly serious impact on medical resources.

The effects of the infection prevention and control measures endorsed as the new normal and new travel etiquettes(scenarios S1–S4) were, in comparison with the peak number of patients hospitalized with serious symptoms with cancelling tourism (Scenario B0), 212% if tourists are accepted without countermeasures (Scenario B1); 183% with voluntary closures of nightlife districts (Scenario S2); 167% with a thorough reduction in contact among workers (Scenario S3); and 159% with a combination of voluntary closures of nightlife districts, a thorough reduction in contact, and isolation of infected people (Scenario S4).

Next, in addition to a thorough reduction in contact and the isolation of infected people, the effects of composite prevention and control measures also including regular prioritized virus tests for workers in contact with tourists (scenarios S5–S10) were 149% with a 50% test ratio every 2 weeks (Scenario S5), 138% with a 75% test ratio every 2 weeks (Scenario S6), and 128% with a 100% test ratio every 2 weeks (Scenario S7) in comparison with Scenario B0 of the peak number of patients hospitalized with serious symptoms. For tests conducted every 5 days, it was 128% with a 50% test ratio every 5 days (Scenario S8), 103% with a 75% test ratio every 5 days (Scenario S9), and 99% with a 100% test ratio every 5 days (Scenario S10).

In addition to a thorough reduction in contact and the isolation of infected people, the effects of composite prevention and control measures also including the implementation of tracking tests for persons in close contact (scenarios S11–S16) were, in comparison with Scenario B0 of the peak number of patients hospitalized with serious symptoms, 133% with a forward one-time tracking ratio of 50% (Scenario S11), 117% with a forward two-time tracking ratio of 50% (Scenario S13), 106% with a forward two-time tracking ratio of 80% (Scenario S14), and 59% with a forward two-time and back one-time tracking ratio of 80% (Scenario S16).

According to the analysis based on the actual measurement data of movement of people and number of infected people, in Nagano prefecture, which includes the target tourism location, the number of newly confirmed positive cases increased as the estimated number of influxes of infected people increased [31]. This tendency was remarkable in the early period of infection expansion, which is the target of this study: the first half of 2020. From the viewpoint of pattern-oriented scenario analysis, this qualitatively corresponds to the pattern of the increase in total cases brought about by a continuous influx of tourists, as shown in Figure 6.

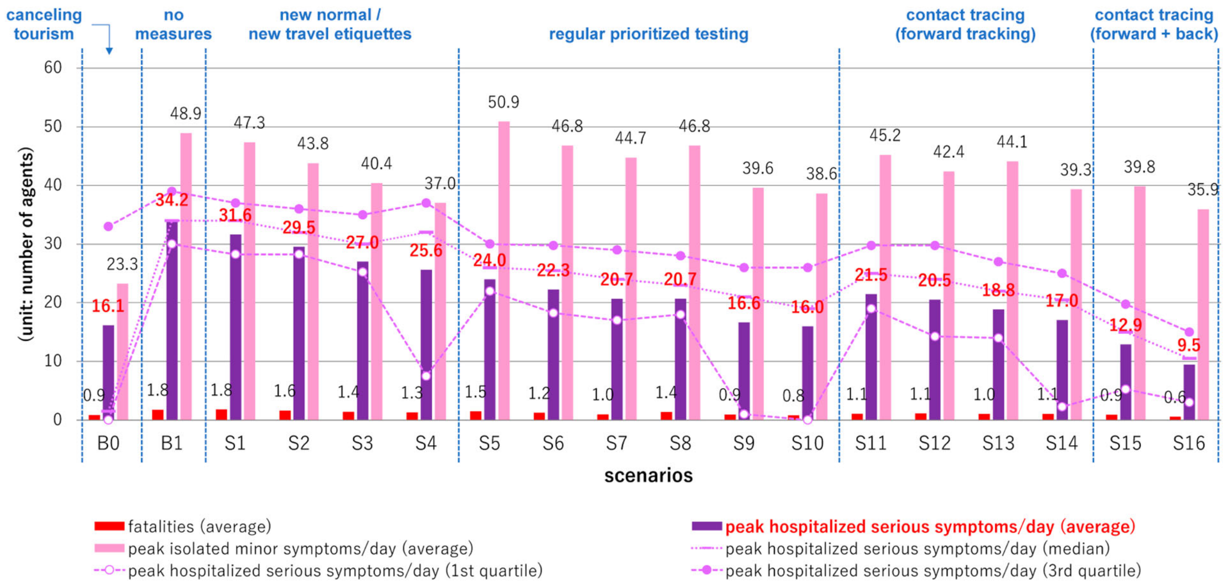

Figure 7. Comparison of the effectiveness of preventive measures on fatalities and peak patients.

5. Discussion

The experiment results demonstrate that there are limited effects even when changes are made to tourist lifestyles or to hospitality business service methods in regions such as tourism locations that are intermittently visited by infected people.

The discovery of infected people by means of substantial PCR testing at the regional level is expected to have an effect on reducing infection. Still, uniform testing for all regional residents is limited, so the effects of regular PCR tests were evaluated with regard to workers in contact with tourists in commercial stores, tourist spots, accommodation facilities, and entertainment districts. As a result, with a test ratio of 75% every 5 days, it was found that the effect on infection control was almost the same as that of prohibiting tourism. As the regional characteristics with regard to a large number of tourism employees are reflected, in this case, the model calls for testing of approximately 2% of the population of the entire region per day. In Japan, the maximum testing capacity per day for PCR tests as of December 2020 is approximately 0.07% (91,610 tests [32] out of 126.5 million people), which does not reach 1/25 of the testing standard mentioned above. For example, Daegu City (approximately 2.4 million people), South Korea, established a testing system for up to approximately 7000 (0.3% of the population) per day [33] in the epidemic before the pandemic and served it to resolve the situation. However, even with this, there is a large gap from the testing standard mentioned above.

For prospective surveys of persons in post-infection close contact with those testing positive for infection and the implementation of tracking tests, almost the same effects are forecast with a two-stage 70% tracking ratio. Also, PCR test numbers in tracking surveys can limit the figure to around 1/10–1/100 in comparison with regular PCR testing for all workers in the hospitality industry. Furthermore, for retrospective surveys not only for persons in post-infection close contact with those testing positive for infection but also in the areas around the people who are the source of infection and the implementation of tracking tests, even in comparison with not accepting tourists, hospitalized patients can be kept under 60%.

However, such surveys require the construction of systems that enable large-scale information collection and processing across large areas and over a long period of time. Therefore, the capacity is limited when relying only on the efforts of public health center workers, for example. And if infection expansion continues and the labour required for the survey expands likewise, the survey system and even the medical system are at risk of collapse. Therefore, the construction of comprehensive survey systems that utilize IT, including tracking persons in close contact by means of mobile phones, etc., is expected to have a major effect on the prevention of increased infection. To this end, in addition to designing a top-down system, the key is to increase the users of COCOA [30] and other contact tracing apps to contribute to a bottom-up system. The experiment results indicate that the major factors include the delay between positive confirmation and app registration, in particular, and the delay between app notification and PCR testing and the ratio of the latter, as well as compliance with home isolation while waiting for PCR test results. As targets for infection prevention and control, from now on, the app usage ratio should be 80% both in the region and among visitors, and the delays should each be one day or less between positive confirmation and notifying persons in close contact.

In Japan, in addition to the continuing low capacity for PCR testing, there are major barriers to access to tests for residents, namely decisions made by doctors and the fact that voluntary testing is not covered by insurance [34]. So sufficient testing systems have not been constructed to implement any of the infection prevention and control measures described above. Regardless of whether or not the region is a characteristic tourism location, for residents who want to be tested after becoming aware that they may have been infected or infect others, testing is to be implemented without delay, allowing for subclinical cases, to identify infected people. Through the construction of a system with bottom-up aspects of this kind, for the first time, it will be possible to accurately grasp the infection situation, the highest priority for public health. This pandemic is still full of uncertainties regarding, for example, the development and distribution schedule for a vaccine and the pathology of after-effects. Therefore, it is desirable to invest pertinent resources promptly to minimize the damage to citizens' health and to the economy to the extent possible.

6. Conclusion

6.1. Research achievement

To evaluate the COVID-19 infection prevention and control measures in tourism locations, this study compared 16 types of infection prevention and control measures by constructing simulation models in imitation of specific tourism locations. The models were based on two types of analytical results (CCDC, WHO) on the basis of detailed restored population data in tourism locations primarily in Nagano Prefecture and on records of 72,314 infected patients in Wuhan. Further, as part of public health policy to prevent and control infection, analyses of tourist contact reduction measures, regular PCR testing for tourism business employees, and prospective tracking tests for people in close contact with those testing positive for infection were conducted. As a result of the simulated experiments, while there are certain effects from measures to reduce contact, it was found that the effects are limited in the case of a continuous influx of infected people to tourism locations. While major effects can be expected from the regular PCR testing of tourism business employees, this requires large-scale PCR testing, which is currently a major barrier. Although there are also major effects from prospective tracking tests for people in close contact with those testing positive for infection, there is a limit to methods that rely only on human labour. While the introduction of contact tracing apps is effective as a countermeasure therefore, there is a need for further improvement in the registration delay time and the implementation systems for prompt PCR testing after notification.

6.2. Future work

This study aimed to estimate the spread of infection under the limited situation that infection in tourism locations had not been observed in detail during the early period of infection expansion. However, data on actual phenomena and their analysis are being accumulated day by day. Furthermore, the situation is constantly changing due to uncertainties such as the establishment of new treatments and the emergence of mutant viruses with different infectivity. Update of the model reflecting these is very much the key component in future attempts to overcome the limitation of this study.

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References

[1] Japan Tourism Agency. Go To Travel campaign official website. 2020. Available from: https://biz.goto.jata-net.or.jp/.

[2] Japan Tourism Agency. Change in the treatment of Tokyo in Go To Travel campaign (updated on September 18, 2020). 2020. Available from https://biz.goto.jata-net.or.jp/info/202009160.html.

[3] Saito T. Economic loss by coronavirus crisis 13.3 'trillion yen for the first quarter of fiscal 2020'. Nihon Keizai Shimbun July 14, 2020.

[4] Okinawa Times. Economic loss of 186.7 billion yen in Okinawa. Okinawa Times Plus April 4, 2020.

[5] Japan Tourism Agency Strategy Planning Division. Travel/tourism consumption trend survey of 2019

annual. 2020. Available online: https://www.mlit.go.jp/kankocho/siryou/toukei/content/001342441.pdf.
[6] Fanelli D, Piazza F. Analysis and forecast of COVID-19 spreading in China, Italy and France. Chaos, Solitons & Fractals. 2020;134:109761.
[7] Dehning J, Zierenberg J, Spitzner FP, et al. Inferring change points in the spread of COVID-19 reveals the effectiveness of interventions. Science. 2020;369:eabb9789.
[8] Kissler SM, Tedijanto C, Goldstein E, et al. Projecting the transmission dynamics of SARS-CoV-2 through the postpandemic period. Science. 2020;368(6493):860–868.
[9] Hellewell J, Abbott S, Gimma A, et al. Feasibility of controlling COVID-19 outbreaks by isolation of cases and contacts. The Lancet Global Health. 2020;8(4):e488–e496.
[10] Tuite AR, Fisman DN, Greer AL. Mathematical modelling of COVID-19 transmission and mitigation strategies in the population of Ontario, Canada. CMAJ. 2020;192(19):E497–E505.
[11] Epstein JM, Cummings DA, Chakravarty S, et al. Toward a containment strategy for smallpox Bioterror: an individual-Based computational approach. Washington, D.C: Brookings Institution Press; 2004.
[12] Epstein JM. Generative social science: studies in agent-based computational modeling. Vol. 13. Princeton (NJ): Princeton University Press; 2006.
[13] Ohkusa Y. An evaluation of counter measures for smallpox outbreak using an individual based model and taking into consideration the limitation of human resources of public health workers. J Health Care Med Commun. 2006;16(3):275–284.
[14] Liu F, Enanoria WT, Zipprich J, et al. The role of vaccination coverage, individual behaviors, and the public health response in the control of measles epidemics: an agent-based simulation for California. BMC Public Health. 2015;15(1):447.
[15] Hunter E, Mac Namee B, Kelleher J. An open-data-driven agent-based model to simulate infectious disease outbreaks. PLoS ONE. 2018;13(12):e0208775.
[16] Kurahashi S. A health policy simulation model of Ebola haemorrhagic fever and Zika fever. Agent and multi-agent systems: technology and applications. Springer; 2016. p. 319–329.
[17] Kurahashi S. Agent-based health policy gaming and simulation for Ebola haemorrhagic fever. Stud Simul Gaming. 2017;26(2):52–63.
[18] Kurahashi S. An agent-based infectious disease model of rubella outbreaks. Agents and multi-agent systems: technologies and applications 2019. Springer; 2020. p. 237–247.
[19] Ferguson N, Laydon D, Nedjati Gilani G, et al. Report 9: impact of non-pharmaceutical interventions (NPIs) to reduce COVID19 mortality and healthcare demand. Imperial College London; 2020.
[20] Silva PC, Batista PV, Lima HS, et al. COVID-ABS: an agent-based model of COVID-19 epidemic to simulate health and economic effects of social distancing interventions. Chaos, Solitons & Fractals. 2020;139:110088.
[21] Aleta A, Martín-Corral D, Piontti AP y, et al. Modelling the impact of testing, contact tracing and household quarantine on second waves of COVID-19. Nat Hum Behav. 2020;4(9):964–971.
[22] Kurahashi S. Estimating effectiveness of preventing measures for 2019 novel coronavirus diseases (COVID-19). Trans Japanese Soc Artificial Intell. 2020;35(3): DK28_1 D–K28_1 .
[23] Harada T, Murata T. Reconstructing prefecture-level large-scale household composition using parallel computing. Trans Soc Instrum Control Eng. 2018;54(4): 421–429.
[24] The Novel Coronavirus Pneumonia Emergency Response Epidemiology Team. The epidemiological characteristics of an outbreak of 2019 novel coronavirus diseases (COVID-19) – China, 2020. China CDC Weekly. 2020;42(2):145–151. doi:10.3760/cma.j.issn.0254-6450.2020.02.003.
[25] WHO-China Joint Mission Team. Report of the WHO-China Joint Mission on Coronavirus Disease 2019 (COVID-19). World Health Organization (WHO); 2020. Available from: https://www.who.int/docs/default-source/coronaviruse/who-china-joint-mission-on-covid-19-final-report.pdf.
[26] Tokyo Metropolitan Government. Countermeasures against novel coronavirus disease – Transition in the number of positive cases by onset date. 2020. Available from: https://www.fukushihoken.metro.tokyo.lg.jp/smph/tthc/kansensho/singatakorona.html.
[27] Novel Coronavirus Expert Meeting. Situation analysis/advice about novel coronavirus disease (March 19, 2020). Ministry of Health, Labour and Welfare; 2020. Available from: https://www.mhlw.go.jp/content/10900000/000610566.pdf.
[28] Novel Coronavirus Expert Meeting. Situation analysis/advice about novel coronavirus disease (April 1, 2020). Ministry of Health, Labour and Welfare; 2020. Available from: https://www.mhlw.go.jp/content/10900000/000617992.pdf.
[29] Grimm V, Railsback SF. Individual-based modeling and ecology. Vol. 8. Princeton (NJ): Princeton University Press; 2005.
[30] Ministry of Health, Labour and Welfare. COVID-19 Contact-Confirming Application (COCOA). 2020. Available from: https://www.mhlw.go.jp/stf/seisakunitsuite/bunya/cocoa/00138.html.
[31] Office for Novel Coronavirus Disease Control: Cabinet Secretariat, Government of Japan. Indexing the risk of infection spread focusing on the possibility of inflow of infected people (updated on July 12, 2021). 2021. Available from: https://corona.go.jp/dashboard/pdf/inflow_risk_20210712.pdf.
[32] Ministry of Health, Labour and Welfare. Novel coronavirus disease – situation in Japan. 2020. Available from: https://www.mhlw.go.jp/stf/covid-19/kokunainohasseijoukyou.html.
[33] Sorihashi K. Kobe City shares wisdom with Daegu City, South Korea about COVID-19. Mainichi Shimbun [Kobe version] August 12, 2020.
[34] Tokyo Metropolitan Government Bureau of Social Welfare and Public Health, Information about novel coronavirus disease. 2020. Available from: https://www.fukushihoken.metro.tokyo.lg.jp/smph/tthc/kansensho/singatakorona.html.