Myoko Model for Balancing Infectious Disease Control and Local Economy

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***Abstract*—Under the situation where the resolution of 2019 novel coronavirus diseases (COVID-19) cannot be foreseen, tourism locations have continued to be exposed to the risk that receive intermittent influxes of people from other regions. Therefore, it is an urgent issue to establish countermeasures for accepting tourists. Based on this background, this study designed an agent-based model that can simulates a spreading infection process, brought by a continuous influx of tourists, among regional residents. This study compared the COVID-19 control measures in tourism locations by simulation experiments. As a result, it was found that certain effects can be expected from active epidemiological investigation. Greater effects can also be expected from the regular testing of tourism business employees, but large-scale testing is currently a major barrier. While the introduction of contact tracing apps is effective as a countermeasure therefore, there is a need for further improvement.**

***Index Terms*—COVID-19, agent-based simulation, epidemic model, tourism, policy science**

I. INTRODUCTION

On October 1, 2020, in view of the governmental update that the situation of COVID-19 infections in Japan was under control, the ”Go To Travel” campaign was executed in full with the aim of economic stimulation in tourism areas by promoting consumption [1]. After that, it was not until the arrival of the worst third wave ever is clarified at the end of December that the tourism promotion established by the directive to ”make Japan better through travel” had been not completely canceled. Elsewhere, preliminary calculations were announced stating that the gross domestic product (GDP) for the full year of 2020 had decreased by 4.8% because of COVID-19 and that economic losses were expected to reach 30 trillion yen [2]. 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, which 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 [3]. Total domestic travel and tourism expenditure in 2019 including inbound tourism was 27.9 trillion yen [4], so there were serious concerns that the ”evaporation” of the tourism demand supporting regional economies would cause critical disruption thereof. Therefore, this study models 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 with consideration for the effects both on those directly involved in the target regions and on others. The purpose of this study is not to discuss the superiority or inferiority between a bottom-up approach in terms of personal behavior, such as avoiding the three Cs (closed spaces, crowded places, and close-contact settings) and voluntarily restricting movement, and a top-down approach in terms of strong government restrictions, such as the declaration of a state of emergency. Rather, this study examines the idea of infection prevention and control measures that enable the continuous growth of the entire region, without bound by such categories.

A. COVID-19 agent-based 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. Agent-based models excel at the manifestation of effects through micro-level behavioral changes among individual citizens as specific intervention measures against infection, as well as at operability based on intervention scenario finding. Therefore, they are used with existing infectious diseases, such as smallpox [5] [6] [7], measles [8] [9], Zika fever [10], Ebola hemorrhagic fever [10] [11], and rubella [12]. As for the proposed COVID-19 simulations, most are based on macro-scale mathematical models including the studies, but there are also some interesting agent-based models. Ferguson et al. [13] reports 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. 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. [14] 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. Aleta et al. [15] 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. D'Orazio et al. [16] suggested that a reduction of virus spreading in public buildings "emerges" from individuals' protection measures, such as facial masking, by using an agent-based model which can jointly simulate people's movement and virus transmission . Then, D'Orazio et al. [17] suggested that such individuals' protection measures are also keys to sustainable economic activities in touristic urban areas, by a similar approach.

B. Summary of related studies and positioning of this study

These studies demonstrate that the use of an agent-based model is possible but do not sufficiently verify the effects of non-medical interventions with attention to the heterogeneity of residents' daily lives and their close relations to these interventions when a vaccine or antiviral drug is not available. Further, there are also not adequate 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 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. The remainder of this paper is organized as follows. Section 2 describes the COVID-19 agent-based experimental model which can evaluate various non-medical infection prevention and control measures. Section 3 explains the experimental scenarios assuming the implementation of the measures to prevent and control infection. Section 4 discusses the experimental results. Section 5 concludes this paper by describing the research achievements.

II. COVID-19 INFECTION MODEL FOR TOURISM LOCATIONS

As an expansion of existing infectious disease studies in which validity evaluations have been conducted for the transition of infection—namely an Ebola hemorrhagic fever model [11] and a rubella model [12] —a COVID-19 model [18] was constructed for Myoko City in Niigata Prefecture. The model uses restored population data created with the household composition restoration method [19], 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 simulated annealing 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, scale of business, etc. Using this data, FIG. 1 shows the population distribution of the target city. 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 valley-shaped terrain is traversed by a local railroad, with residential areas distributed next to the line. Most of the population is concentrated in the north, forming an urban area integrated with the center of Joetsu City, where the terminal station is located. In addition, there are many ski and hot spring resort areas at the foot of the mountains in the southeast and southwest.

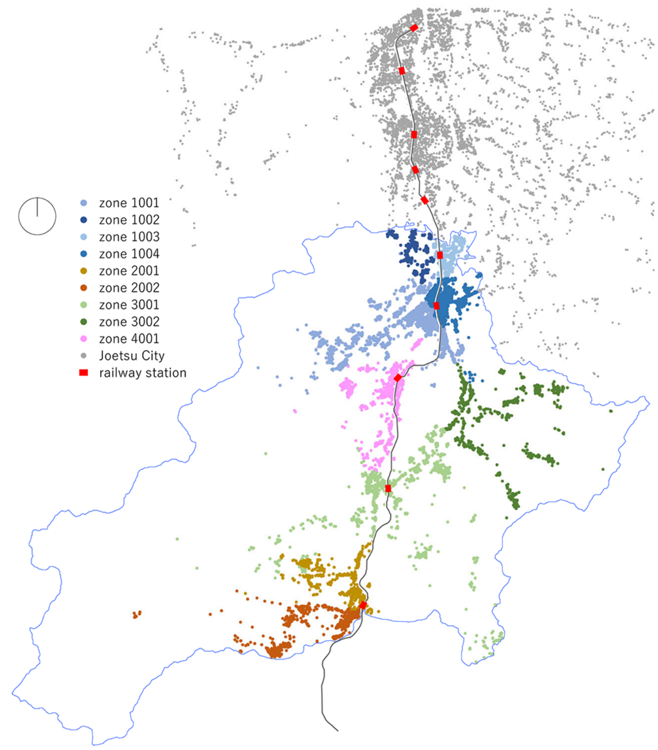

FIG. 1. POPULATION DISTRIBUTION OF MYOKO CITY

The total population based on the restored population data is approximately 31,500 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 zone, etc. were set according to the actual population composition (see TABLE I).

TABLE I. POPUPATION COMPOSITION

	actual city	model
population	31,560	6,000
number of households	11,854	2,295
average household size	2.66	2.61
0-29 years old (young)	25.3%	25.0%
29-64 years old (adults)	44.6%	45.7%
65- years old (elderly)	30.3%	29.3%
average age	50.4	-

TABLE II shows the model household composition. Actually, infection spreads through diverse and complex routes, based on people's heterogeneity, such as age and lifestyle. Therefore, by implementing such demographic information in the model, it is possible to simulate the complex behavior of infection.

TABLE II. MODEL HOUSEHOLD COMPOSITION

househould composition	households	population
single (adult)	200	200
single (elderly)	300	300
couple (adults)	125	250
couple (elderly)	400	800
couple + one child	300	900
couple + two children	250	1,000
one parent + one child	250	500
couple + parents	50	200
couple + onw parent	100	300
couple + one child + parents	40	200
couple + two children + parents	100	600
couple + one child + one parent	150	600
couple + two children + one parent	30	150
total	2,295	6,000

A. *Behavior of citizen*

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. 66% of young people—that is, 17% of the total population—attended childcare facilities or school. There were 10 childcare facilities, nine elementary schools, and four junior high schools in the city, as well as one senior high school in the city and four outside. 70% of the remaining young people, 80% of adults, and 20% of the elderly—that is, 48% of the total population—were workers. This corresponds to a 48.3% total employment ratio in the restored population data. TABLE III shows the employment locations of workers.

TABLE III. EMPLOYMENT LOCATIONS OF WORKERS

employment locations	ratio
hospitality industry	**15%**
local shop of 11	
tourism spot of 5	
large hotel of 4	
small hotel of 10	
night spot of 3	
education	**3%**
childcare facility of 10	
elementary school of 9	
junior high school of 4	
senior high school of 5 (1 in the city and 4 outside)	
medical and welfare	**3%**
large hospital of 2	
nursing home of 8	
other employment location (in the city)	**39%**
other employment location (outside city)	**39%**

The area has many popular tourist locations, and the ratio of employees at wholesale or retail businesses, accommodation, or food service businesses and daily life-related services and entertainment businesses was 26%. Reflecting this, the ratio of workers in actual customer-facing roles was set at 15%, 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 are established near local railway stations in the model area, with their employees set as residents of nearby zones. These local shops refer to retail stores, such as supermarkets and restaurants that are mainly served to local residents. However, tourists also use the two in the south, near the resort areas in the southeast and southwest. Tourism spots, hotels, and night spots are located in the southeastern and southwestern resort areas, with the majority of their employees living in nearby zones. Some of the resident agents other than workers at local shops and residents of nursing homes go shopping at local stores neighboring to their residential zones after work or school. Finally, all resident agents other than hospital inpatients go home.

FIG. 2 shows the household and facility distribution in the model space.

B. *Progress of infection and symptoms*

In each round of simulations, infection was modeled on localized interaction among resident agents. Resident agents were activated sequentially in random order; in the case of contact with other resident agents who were infected on the model plane, the contact ratio cr was 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, was defined as follows.

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

This infection probability defines how much a nearby infected person infects each agent. This probability was set so that the expected value would be the same based on the basic reproduction number R0 (2.5) of COVID-19 and the estimated contact time of the inhabitants per day at each contact scene such as workplace, school, home, and so on.

Based on reports of detailed analyses of the infection prevalence of COVID-19 [20] [21], the following process of the progress of symptoms was 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 diarrhea occur in most infected people. After the fever, the basic scenario included a 50% probability of home isolation after visiting a doctor. 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 polymerase chain reaction (PCR) test with the results confirmed the following day, leading to hospitalization if the results are positive. Regarding the actual number of fatalities, because the estimated number of infected people has been drastically reduced, the test supplementary ratio was set at half (50%). 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

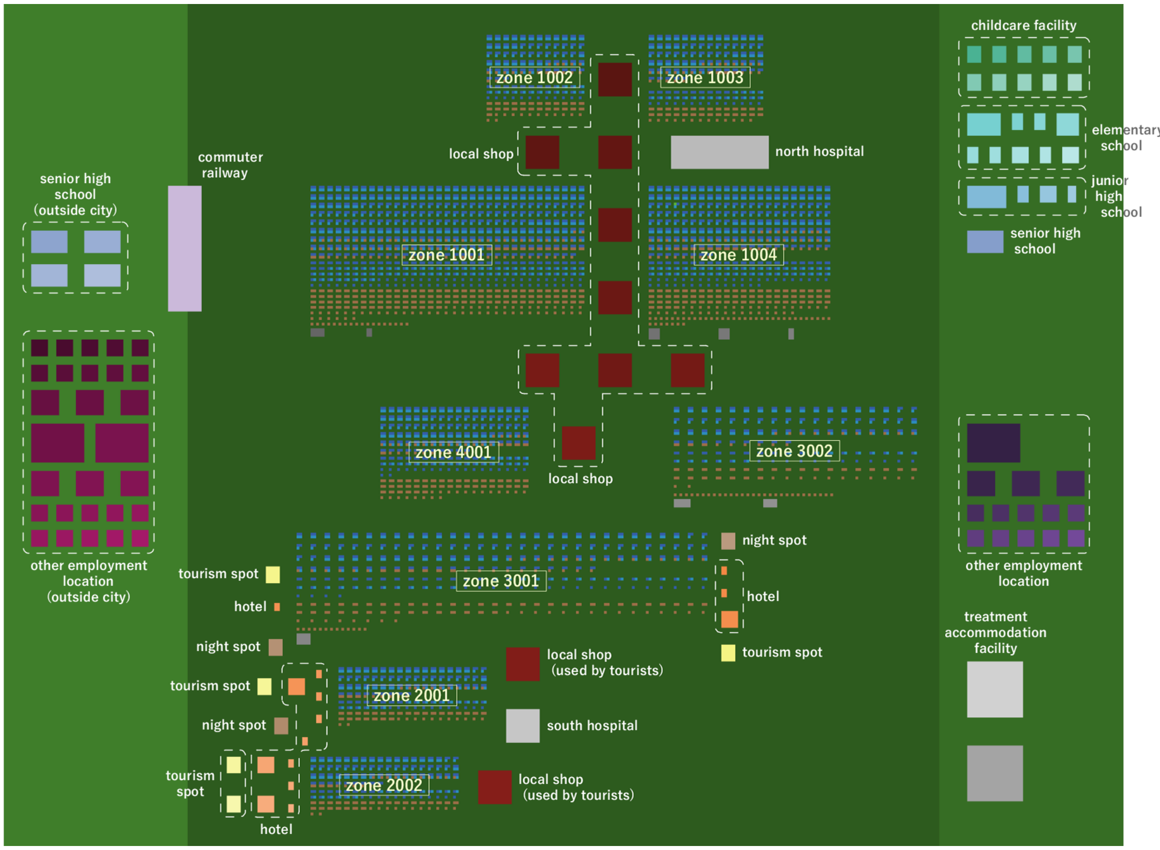

FIG. 2. HOUSEHOLD AND FACILITY DISTRIBUTION

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. The mildly ill recover by 27 days after infection and the surviving seriously ill by 49 days after infection, achieving temporary immunity.

III. 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 may be used by infected tourists. Table IV shows the settings of the scenarios. There are a total of 12 scenarios, defined by whether to accept tourists, infection control at shops, nightspots, tourist spots, quarantine facilities for infected people, degree of tracking close contacts, frequency of PCR tests, and so on.

These infection prevention and control scenarios are roughly divided into four; social distancing (scenarios S1-S2), contact tracing (scenarios S3-S4), regular testing for high-risk workers (scenarios S5-S7), and combination of contact tracing and regular testing (scenarios S8-S11). 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 infectious tourist per week enters. In Scenario S1, local residents' visit to local shops is reduced by 75%; in Scenario S2 local residents' visit to local shops is reduced by 75% and contact between hospitality industry workers and tourists is reduced by 75%. In scenarios S3 and S4, local residents' visit to local shops is reduced by 75%, contact between hospitality industry workers and tourists is reduced by 75%, forward tracking (once) of persons in close contact and PCR tests are implemented, and those testing positive are isolated at a treatment accommodation facility. Here, a forward tracking of persons in close contact with the objective of preventing further infection expansion is implemented by tracking tests, e.g., via interviews and the contact app COCOA, [22], etc. for persons in post-infection close contact with people who have tested positive for infection. The tracking ratio is defined as the discovery ratio of persons in close contact and the infection source. In scenarios S5-S7, local residents' visit to local shops is reduced by 75%, contact between hospitality industry workers and tourists is reduced by 75%, workers undergo regular PCR testing, and those testing positive are isolated at a treatment accommodation facility. In scenarios S8-S11, local residents' visit to local shops is reduced by 75%, contact between hospitality industry workers and tourists is reduced by 75%, forward tracking of persons in close contact and PCR tests are implemented, workers undergo regular PCR testing, and those testing positive are isolated at a treatment accommodation facility.

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TABLE IV. SIMULATION SCENARIOS FOR INFECTION PREVENTION AND CONTROL MEASURES

scenario	tourists	influx of infections	local shop	hotels	night spots	tourism spots	isolation	tracking	regular testing
B0	not accepted	one resident	100%	-	-	-	-	-	-
B1	accepted	one per week	100%	100%	100%	100%	-	-	-
S1	accepted	one per week	25%	100%	100%	100%	-	-	-
S2	accepted	one per week	25%	25%	25%	25%	-	-	-
S3	accepted	one per week	25%	25%	25%	25%	Yes	forward 50%	-
S4	accepted	one per week	25%	25%	25%	25%	Yes	forward 80%	-
S5	accepted	one per week	25%	25%	25%	25%	Yes	-	every 2 wks 50%
S6	accepted	one per week	25%	25%	25%	25%	Yes	-	every 2 wks 75%
S7	accepted	one per week	25%	25%	25%	25%	Yes	-	every 2 wks 100%
S8	accepted	one per week	25%	25%	25%	25%	Yes	forward 50%	every 2 wks 50%
S9	accepted	one per week	25%	25%	25%	25%	Yes	forward 50%	every 2 wks 75%
S10	accepted	one per week	25%	25%	25%	25%	Yes	forward 80%	every 2 wks 50%
S11	accepted	one per week	25%	25%	25%	25%	Yes	forward 80%	every 2 wks 75%

IV. EXPERIMENT RESULTS

Each simulation scenario was implemented 100 times. The infection prevention and control measures were evaluated by the average of the peak number of people hospitalized with serious symptoms, which is the major serious impact on medical resources. The results are shown in FIG. 3.

The average number of mildly infected persons was 14.3 (B1) at the maximum and 2.4 (B0) at the minimum. The infection process has an incubation period of 5 days and a recovery time of 27 days, so the number of new positive cases per day ranges from 0.65 to 0.11, which is 11 to 2 per 100,000. In Tokyo, where the infection was spreading at that time, the number was 14 to 2 per 100,000. Therefore, the average results of the simulation are almost the same as the actual values of Tokyo.

The effects of the voluntary infection prevention and control measures (Scenarios S1 and S2) endorsed as the new normal and new travel etiquettes were, in comparison with the peak number of patients hospitalized with serious symptoms with canceling tourism (Scenario B0), 738% if tourists are accepted without countermeasures (Scenario B1), 385% with reduction in residents' visit to local shops (Scenario S1), and 148% with thorough reduction in contact between workers and tourists (Scenario S2).

Scenarios S3 and S4 were 114% with a forward one-time tracking ratio of 50% (Scenario S3) and 106% with a forward one-time tracking ratio of 80% (Scenario S4) in comparison with Scenario B0. These scenarios include reducing a visit to local shops, 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.

On the other hand, the combined spread prevention measures (scenarios S5 to S7), which carry out regular virus tests on hospitality employees who may come into contact with tourists, reduced the number of infected people. The results are 93% with a 50% test ratio every 2 weeks (Scenario S5), 71% with a 75% test ratio every 2 weeks (Scenario S6), and 63% with a 100% test ratio every 2 weeks (Scenario S7).

Furthermore, the combined spread prevention measures (scenarios S8 to S11), which carries out both follow-up inspections of close contacts and regular virus inspections of hospitality employees, effectively reduced the number of infected persons. In these scenarios, the results were 67% with a forward one-time tracking ratio of 50% and a 50% test ratio every 2 weeks (Scenario S8), 56% with a forward one-time tracking ratio of 50% and a 75% test ratio every 2 weeks (Scenario S9), 59% with a forward one-time tracking ratio of 80% and a 50% test ratio every 2 weeks (Scenario S9), and 53% with a forward one-time tracking ratio of 80% and a 75% test ratio every 2 weeks (Scenario S11).

V. DISCUSSION

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

As a result of evaluating the effect of active epidemiological survey, for prospective surveys and tests in persons close contact with those testing positive, it was found that hospitalized patients can be kept at about the same as that of prohibiting tourism.

The discovery of infected people by means of substantial PCR testing at the regional level is expected to have an effect, but 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, tourism spots, accommodation facilities, and entertainment districts. As a result, it was found that infection control effects were greater than that of prohibiting tourism. However, in Japan, the maximum testing capacity per day for PCR tests as of May 2021 is approximately 0.16% (203,477 tests [23] out of 126.5 million people), which is far below the testing standard of the scenarios where major effects were observed.

Regular PCR tests for just hospitality industry workers have an effect, but there are various barriers to realize it. So the effects of the combination of regular PCR tests and active epidemiological survey were evaluated. As a result, it was found that major effects on infection control were observed while reducing number of tests. However, such surveys also 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

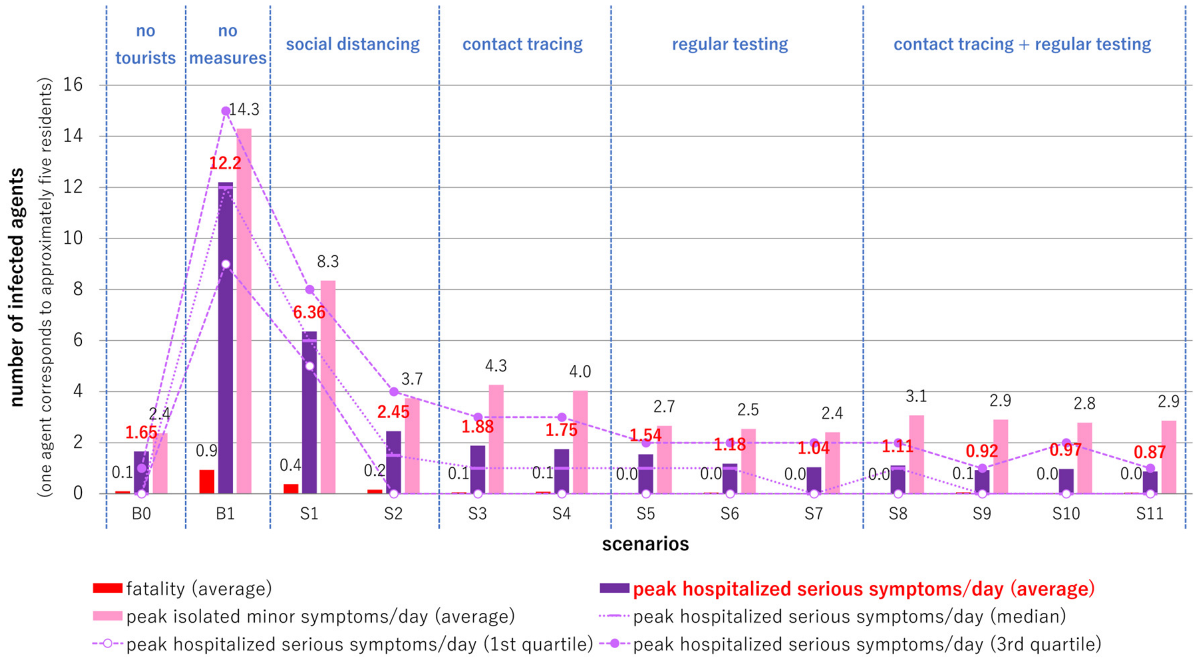

FIG. 3. COMPARISON OF THE EFFECTIVENESS OF PREVENTIVE MEASURES

the labor 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 information technology, 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 and other contact tracing apps to contribute to a bottom-up system. 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 between positive confirmation, app registration, and notifying persons in close contact should each be shortened as much as possible.

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 [24], so sufficient testing systems have not been constructed for the implementation of 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 that they may 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, e.g., the development and distribution schedule for a vaccine, the mutation of the virus, 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.

VI. CONCLUSION

With the objective of evaluating the COVID-19 infection prevention and control measures in tourism locations, this study compared 11 types of infection prevention and control measures by constructing simulation models in imitation of specific tourism locations. As part of public health policy to prevent and control infection, analyses of tourist contact reduction measures, active epidemiological investigation—prospective tracking tests for people in close contact with those testing positive for infection, and regular PCR testing for tourism business employees 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 certain effects can be expected from active epidemiological investigation; while greater effects can also be expected from the regular PCR testing of tourism business employees, this requires large-scale testing, which is currently a major barrier. 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 testing after notification.

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