Shifting workstyle to teleworking as a new normal in face of COVID-19: analysis with the model introducing intercity movement and behavioral pattern

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Background: Instead of the complete lockdown, since the outbreak of coronavirus disease 2019 (COVID-19), Japan has been trying to control the infection by self-restraint request policy. It seems that the number of infected people has subsided, however, the increasing human activities again in the resumption of economy may lead to the second wave of infections. Here, we analyzed the major factors behind the success control of the first outbreak in Japan and the potential risk of the second wave.

Methods: Employing a localized stochastic transition model, we analyze the real data and the results of simulation in Tokyo from March 1 to July 31. In the model, population is divided into three compartments: susceptible, infected, and removed; and area into three zones: crowded, mid and uncrowded. Different zones have different infection probabilities characterized by the number of people gathered there. The flow of the infection simulation in one day consists of three steps: (I) intercity movement of population, (II) isolating infected people, and (III) zone shifting following group behavioral patterns.

Results: The major cause for the success of controlling the first outbreak in Tokyo is demonstrated through our simulation to be the early request of self-restraint as well as the early detection of infected people. Meanwhile, the observation that the increasing human activities again in the resumption of economy will lead to the second wave of infections is also found in the simulation with an extended period. Based on the analysis of intercity movement and behavioral pattern on Tokyo where normally about 2.9 million people come from the surrounding cities to the central area by using the public railway system every day, results showed that turning the workstyle of 55% of working people ranging in age from 20 to 64 years old into teleworking (remote work) may control the spread of infection without significant economic damage. Meanwhile, to keep about 75% of the normal activity level and to advocate the shift to telework are indispensable because a sudden resumption of activity from the lockdown sate can rapidly spread infection.

Conclusions: As a new normal in face of COVID-19 for Tokyo and other cities that with a high population density, shifting the workstyle of 55% of working people to teleworking and to reduce 25% time staying in the high infection risk area could be an effective measure to control the spread of infection while maintaining a certain level of economic activity.

Keywords: Coronavirus disease 2019 (COVID-19); Japan; Tokyo; transmission; infection; modeling; susceptible-infected-removed (SIR)

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Introduction

The outbreak of coronavirus disease 2019 (COVID-19) poses a serious threat to global health and economies. The pathogen has been identified as a novel enveloped RNA betacoronavirus that named severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (1-3). The diagnostic approaches for COVID-19 include nucleic acid detection, chest computed tomographic (CT), epidemiological history and clinical manifestations. It presents a wide range of clinical presentation, from asymptomatic or mildly symptomatic patients to those requiring intensive care (4-6). Currently, hundreds of clinical trials on a wide variety of treatments against COVID-19 are being conducted around the world (7).

On March 11, 2020, the World Health Organization (WHO) declared COVID-19 as a pandemic (8). As of July 11, the number of confirmed cases has increased to 12.4 million and over 559,000 people have unfortunately lost their lives (9). Stringent public health and social measures (PHSM) have been put in place to slow down the spread of COVID-19, and even the measure of complete lockdown has been installed in some cities, such as Wuhan, China.

In Japan, the first domestic COVID-19 transmission was reported in January 2020. As of July 11, there were 21,113 domestic cases have been confirmed, including 981 deaths (10). Japan's death rate per capita from COVID-19 is one of the lowest in the world. Instead of the complete lockdown, since the outbreak of COVID-19, Japan has been trying to control the infection by self-restraint request policy calls for the avoidance of "closed spaces, crowded places, and close-contact settings" to the greatest extent. This policy focuses on reducing the epidemic peak by prioritizing treatment for those who are at risk of developing serious pneumonia, and on avoiding the collapse of public health-care service as well.

Characterized by "limited fatality despite loose restriction" (11), Japan is a country that claims to have succeeded in controlling COVID-19 first outbreak without complete lockdown. In early April, the number of infected people per day in Japan, especially Tokyo, exceeded triple-digits (12,13). The Japanese government declared a state of emergency on April 7 in order to control the spread of infection and urged the people to refrain from unnecessary outings (14). As of May 25, the Japanese government has lifted the state of emergency because the average number of infected people per day fell to below 20 and the risk of large-scale infection spread has been decreased (15). By May 25, there were 16,445 known cases of infection, of which 5,159 were found in Tokyo (16), accounting for about 31% of cases in Japan. It seems that the number of infected people has subsided from April to June, however, after lifting the state of emergency, the increasing human activities again in the resumption of economy may lead to the second wave of infections. In Tokyo, 224 new cases were reported on July 9 and 243 new cases reported on July 10, 2020 (17), and currently, Tokyo is the city with the largest number of confirmed cases of COVID-19 in Japan.

There are some studies analyzing future trends of COVID-19 in Japan (18-20), especially analyzing the peak or increasing trend of infected people. However, the analysis of intercity movement and behavioral pattern with different activity levels by employing a localized stochastic transition model has not been fully investigated. In this study, analysis with the model introducing intercity movement and behavioral pattern is conducted on Tokyo, which has a high population density and is the city with the largest number of confirmed cases of COVID-19 in Japan currently, with the purpose to provide the data reference for COVID-19 epidemic control for Tokyo and other cities worldwide that with a high population density.

In this study, employing a localized stochastic transition model, we analyzed the major factors behind the success control of the first outbreak in Japan and the potential risk of the second wave. Furthermore, based on the analysis of intercity movement and behavioral pattern with different activity levels, we will discuss the effectiveness of suppressing the infection by reducing the amount of activities with non-mandatory restrictions, and propose ways to control the spread of infection while maintaining a certain level of economic activity.

Methods

Localized stochastic transition model

In the previous study, the spread of COVID-19 in Japan was treated as a transmission in a closed system and studied with a stochastic transition model. To this end, we proposed a formulation for the stochastic transition of agents' state with reference to SIR (susceptible-infected-removed) model (18). The considered area is divided into three zones: crowded, mid and uncrowded, which is an abstract area where people spend time and characterized by the number of people. The average time of meal, commute, and work per day for Japanese people is about eight hours, and at that time people spend in an area likely to contact with other people, thus it is considered as a person is staying in a crowded zone. On the other hand, the situation of sleeping is considered as staying in uncrowded zone because there is little contact with people. In addition, the mid zone is an intermediate concept between above two. Different infection rates are applied in different zones. For example, susceptible transitions into infected every hour with a probability determined by both the tag of area zone and the ratio of infected in that zone. Moreover, people migrate among different zones following a uniform behavioral pattern which specify how long they should spend in a certain zone.

In this study, as the focus is on the modeling of the spread of infections in Tokyo area, intercity commuting is added to the previous model by taking into account the transportation characteristics of Tokyo, namely a large influx of population from surrounding cities. In addition, people follow different behavior patterns according to the specific groups to which they belong. The inclusion of non-uniform behavioral pattern is inspired by the observation that, under the government intervention, such as the declaration of state of emergency, recommendations of telework and school closures, people are likely to adopt different behavioral patterns according to their different social status.

Flow of simulation

In Tokyo, normally about 2.9 million people come from outside to the central area by using the public railway system every day (21). Most people come from the surrounding cities for commuting to work or school. We define Tokyo and its surrounding cities, including Chiba, Kanagawa, Saitama, Tochigi, Gunma, and Ibaraki as individual semi-closed systems, and take the intercity movement of people into consideration. Different numbers of susceptible, infected, removed are initialized in different cities according to the real data.

As shown in *Figure 1*, the flow of infection simulation in a single day consists of three steps: (I) intercity movement of population, (II) isolating infected people, and (III) zone shifting following group behavioral patterns and the local infection of susceptible. In step (I), a certain fraction of people is randomly selected in each city and put into another city. People who moved to other cities are temporarily counted as the local person in the destination city within that day. In step (II), all infected in the city are segregated and transition to removed with the removal probability in that city with d defined as date. In step (III), first susceptibles in each city enter into different zones according to behavioral patterns of the group to which they belong. Next, susceptible is infected and transitions to infected with the infection probability $P_{zone,infection}$ (d) on day d. After completing all steps, the commuting people will return to their original cities. All the above steps are repeated as a routine process for each individual in all the cities.

Infection and removed probabilities

The zonal infection probability $P_{zone,infection}$ (d) indicates the rate of getting infected when a susceptible person stays in a specific zone area. Note that each city consists of three zones including crowded zone, mid zone and uncrowded zone, assigned with different zonal infection probabilities. As the zonal infection probability can be influenced not only by the characteristics of the zone but also by the proportion of infected in that city, it is decided as the following

$$P_{zone,infection}(d)=\alpha_{zone}R_{C,Infected}(d) \quad [1]$$

$$R_{C,Infected}(d)=\frac{N_{C,Infected}(d)}{N_C(d)} \quad [2]$$

where α_{zone} denotes the baseline probability of infection in the zone where the susceptible stay, and $P_{c,Infected}$ (d) denotes the ratio of infected in city C on day d. The number of infected and the total number of people in the city are denoted as $N_{C,Infected}$ (d) and N_C (d).

Denoted as $P_{Removed}$ (d), the probability of transition from infected to removed is set independent of cities. It is related to the speed at which infected is detected in reality, which depends on the number of PCR tests performed per day. Correspondingly, $P_{Removed}$ is given by

$$P_{Removed}(d)=\begin{cases}\frac{\beta_{term}}{10} & (if\ d\ is\ holiday)\\ \beta_{term} & else\end{cases} \quad [3]$$

where β_{term} denotes the baseline probability for the removal of

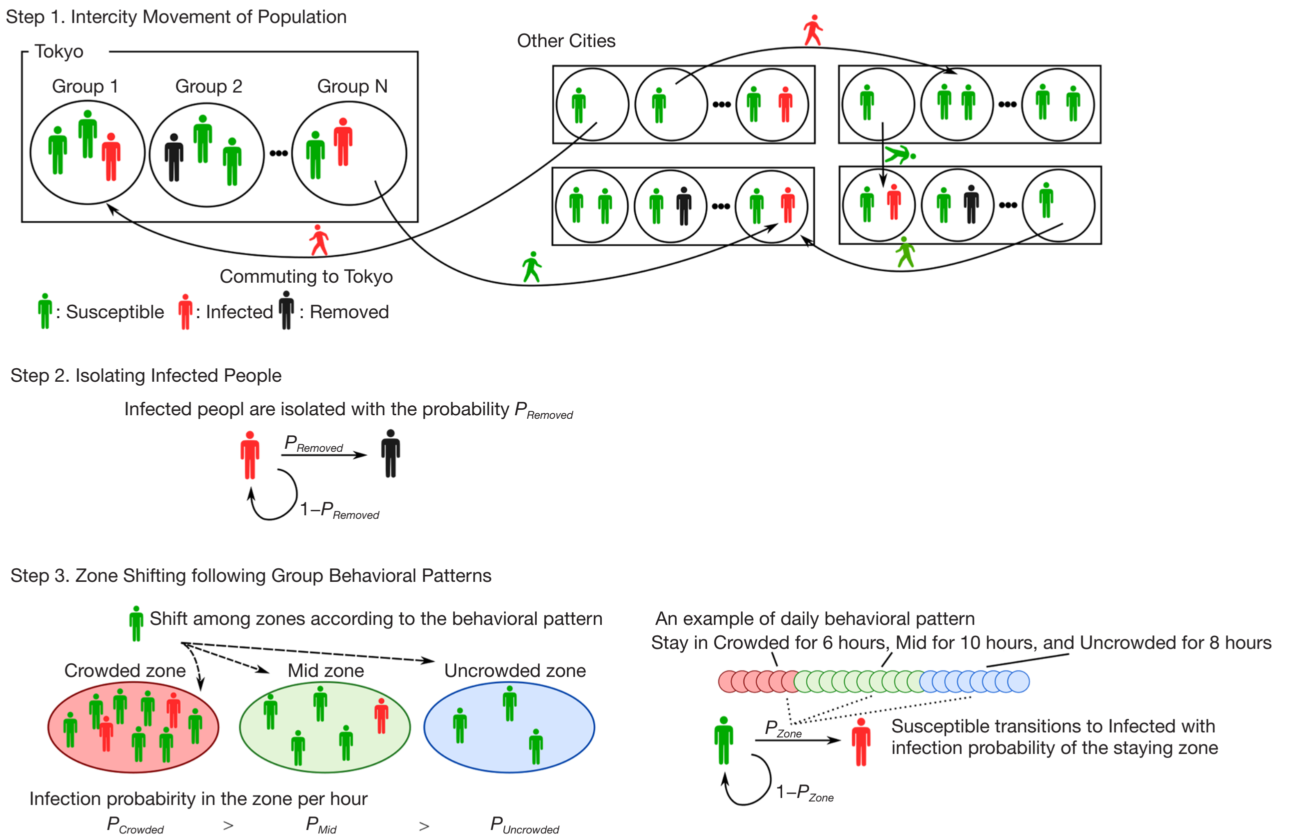

Figure 1 The Flow of localized stochastic transition model in Tokyo.

infected. The simplest model set β_{term} as a constant. However, considering the increase in the number of PCR tests and the widespread recognition of COVID-19 symptom, which makes the disease easier to be detected at an earlier stage, β_{term} can also be shifted upward continuously. The reason for reducing the value to 1/10 on holidays is that the Japanese PCR test institutions have days off.

Grouping of population

To reflect the actual state of Tokyo after March, the population is divided into several groups in consideration of both the age and the effects of declaration of the state of emergency. Three major groups are assembled by age as Group I (under 20 years old), Group II (20 to 64 years old), and Group III (65 years old and over). Group I and Group III are further divided into two sub-groups: A (the normal) and B (the active). Group II is divided into four sub-groups: A (the normal), B (the active), C (complete telework) and D (partial telework). Group II-C and Group II-D stand for the change of working style in response to the declaration of the state of emergency, recommendations to telework and school closures by the Japanese government. Note that each group has a distinct behavior pattern, according to which people decide the duration in which they stay in the three zones.

Results

Simulation of infection spread before lifting the state of emergency in Tokyo

The infection spread from March 1 to May 24 (before lifting the state of emergency) in Tokyo were analyzed, model parameters were set as $\alpha_{crowded\ zone}$ =2%, $\alpha_{mid\ zone}$ =0.2%, and $\alpha_{uncrowded\ zone}$ =0.02% with reference to the values used in the previous study (18).

Table S1 shows the initial number of people in each group and the initial number of people who are susceptible, infected, or removed. The total population and age distribution for each city are set with reference to the values

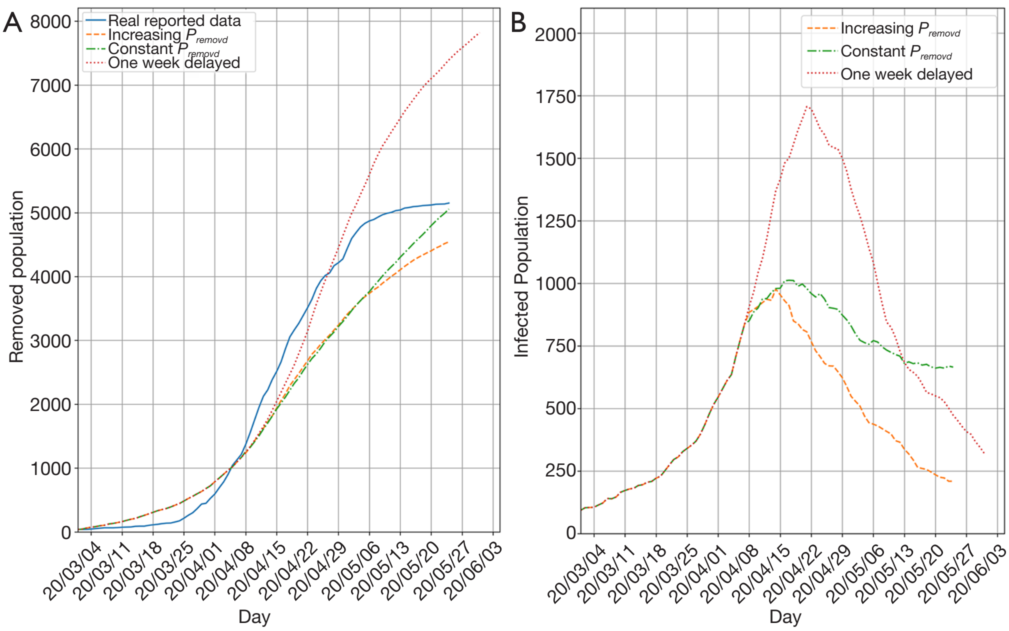

Figure 2 Infection transition in Tokyo of the real data and the results simulated by localized stochastic transition model. (A) Transition of the number of removed or people reported as COVID-19. (B) Transition of the number of infected.

announced by each prefecture (22-28). The initial number of removed in each city is set as the number of infected persons found in each city as of February 29 (29). The initial number of susceptible in Tokyo is set as 2.5 times the number of removed, and the initial number of susceptible in other city is set as 1.5 times the number of removed. Initial values of removed and susceptible are assigned to each group according to the age distribution of infected person in Japan (29). Based on the fact that the number of train passengers declined in Tokyo in March (30), 25% of Group II members (20 to 64 years old) is put into the C subgroup (complete telework) and 35% of the group members is put into the D subgroup (partial telework). Moreover, 10% of the total members in Group I, II and III belong to the active subgroup, while the rest belongs to the normal subgroup.

Table S2 shows the baseline removal probability, from March 1 to May 24, the day right before the state of emergency declaration was lifted. There are two settings of β_{term} for comparison, one as a constant and the other as an increasing value. *Tables S3* and *S4* display the number of people commuting between cities and the behavioral patterns for each group during the same period. The behavioral pattern of each group is adjusted so that people stay in three zones for an average of 8 hours.

A virtual scenario is also simulated under the assumption that the declaration of state of emergency was delayed to April 14. Behavior patterns are the same as above, except that all the dates shift one week forward.

Simulation results with parameters above and the actual cumulative number of people confirmed as COVID-19 in Tokyo are shown in *Figure 2*. In addition, the transitioning number from susceptible to removed per day in the simulation and the actual growth number of people confirmed as COVID-19 in Tokyo (13) are shown in *Figure 3*.

As shown in *Figure 2*, with an increasing removal probability, the number of infected reaches 4,576 on May 24, while the actual number is 5,151. In *Figure 3*, the transitioning number from susceptible to infected with an increasing removal probability reaches its peak around April 16 and converges around May 21, similar to the actual data in Tokyo, On the other hand, the fixed removal probability makes no difference to the timing of infected peak, but it delays the process of convergence. Lastly, it can be seen that if the declaration of the emergency state were delayed by one week, the number of infected would be enlarged and eventually reach the peak number more than 1.5 times the actual number of persons confirmed as COVID-19 in Tokyo.

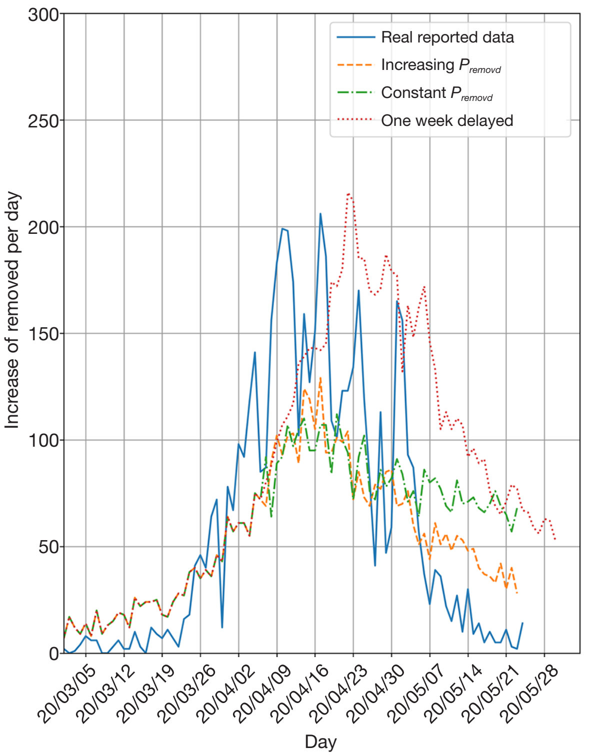

Figure 3 Increase of removed and people reported as COVID-19 per day in Tokyo.

Simulation of infection spread after lifting the state of emergency in Tokyo

The state of emergency was lifted on May 25, though there is still a probability of another wave of infection coming to the great Tokyo area. In this study, the spread of infection is further simulated up to July 31, 2020 under several possible scenarios. Results from March 1st to May 24, including the population of susceptible, infected and removed, are used as initial conditions and the increasing removal probability $P_{Removed}$ is applied to the subsequent simulations.

Behavioral patterns are specified for six scenarios as shown in *Table 1*. The behavioral pattern of Scenario A is identical with that used in March, except Group IA members are allowed to go to school. In Scenarios B and C, the active members of each group reduce their duration of stay in the crowded zone to 75% and 50% of that in Scenario A, respectively. In Scenarios D, E and F, durations of stay in the crowded zone are set uniformly to 8, 6 and 4 hours irrespective of the characteristics of different subgroups.

Predictions of the spread of infection from May 25 to July 31 under different scenarios are shown in *Figure 4*. For Scenarios A and D, in which activities are almost recovered to the normal level, it can be seen that the number of removed increases by 5,000 in two months. For Scenarios B and E, the number of removed increases almost constantly and reaches about 2,000 in two months. Subsiding of the spread of infection can only be observed in Scenarios C and F where the size of infected population decays gradually.

Effects of increasing telework population

The result of Scenario A shows that occurrence of the second wave of infections is possible if the activity level returns to that in March, before the declaration of the emergency state. On the other hand, the government has been promoting telework since late February. Correspondingly, complete telework has been realized in some companies, however, only the partial telework is implemented in others.

Scenarios A and B are used as reference, where 25% of Group II (from 20 to 64 years old) members are completely doing the telework. To compare with the reference scenarios, new scenarios are added as A40/B40, where 40% of Group II members are set as the complete teleworkers; and also as A55/B55, where 55% of the same group members are set as the complete teleworkers. Results of predicting the control of infection spread under the new scenarios are shown in *Figure 5*. In Scenarios A40 and B40, the effect of shifting to telework is negligible and the infected number reaches almost the same level in Scenarios A and B. On the other hands, the number of infected decreases gradually in Scenarios A55 and B55 showing that the shift to telework is effective, only if more than half of the workers respond to the government's promotion.

Discussion

The famous SIR epidemiological model was mainly used in previous studies on analysis and prediction of the COVID-19 epidemic in Japan (18-20). The main difference between the model used in the current study and SIR model is the inclusion of locality and heterogeneity. With the localization, intercity movements can be taken into account so that the increase of infected number in late March in the Kanto area caused by the influx/outflux of population to/from Tokyo can be well captured. On the other hand, the application of heterogeneous behavioral pattern to different groups of population render our model closer to the realistic

Table 1 Behavioral pattern of each group that represents the time spent per day in each zone for different activity scenarios after lifting the state of emergency

Scenario	Term	Zone	Time staying at each place per day (hour)															
			Age: 0–19				Age: 20–64								Age: 65~			
			Normal		Active		Normal		Active		Complete telework		Partial telework		Normal		Active	
			Weekdays	Holidays	Weekdays	Holidays	Weekdays	Holidays	Weekdays	Holidays	Weekdays	Holidays	Weekdays	Holidays	Weekdays	Holidays	Weekdays	Holidays
A	05/25–07/31	Crowded	8	8	12	12	10	10	12	12	4	8	10	10	6	6	12	12
		Mid	8	8	6	6	6	6	6	6	12	8	6	6	10	10	6	6
		Uncrowded	8	8	6	6	8	8	6	6	8	8	8	8	8	8	6	6
B	05/25–07/31	Crowded	6	6	9	9	8	7	9	9	4	6	8	7	4	5	9	9
		Mid	10	10	7	7	8	9	7	7	12	10	8	9	12	11	7	7
		Uncrowded	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
C	05/25–07/31	Crowded	4	4	6	6	5	5	6	6	4	4	5	5	3	3	6	6
		Mid	12	12	10	10	11	11	10	10	12	12	11	11	13	13	10	10
		Uncrowded	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
D	05/25–07/31	Crowded	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
		Mid	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
		Uncrowded	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
E	05/25–07/31	Crowded	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
		Mid	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
		Uncrowded	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
F	05/25–07/31	Crowded	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
		Mid	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
		Uncrowded	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8

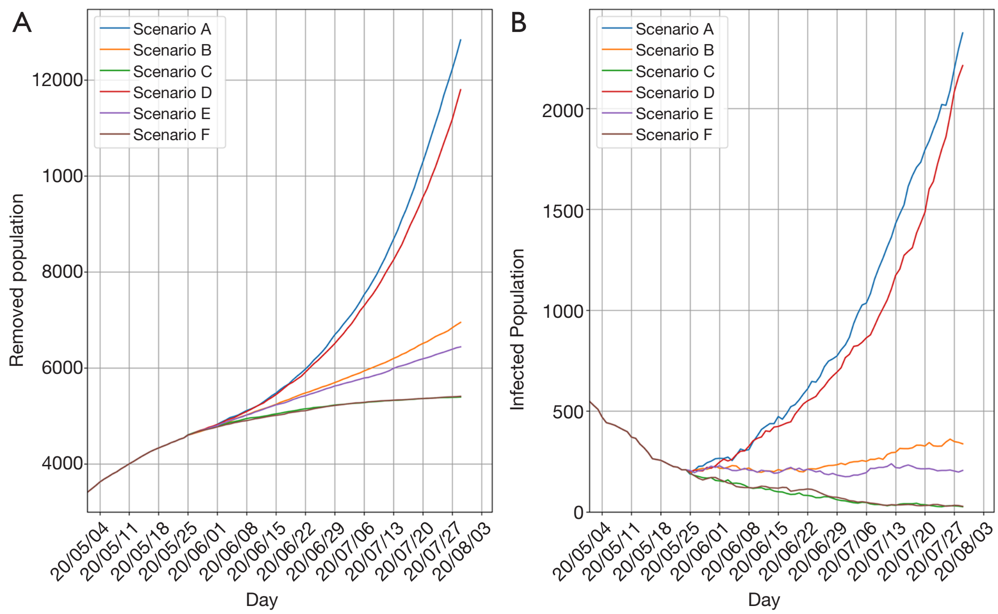

Figure 4 Infection transition in Tokyo predicted in scenarios with different activity levels by localized stochastic transition model. (A) Transition of the number of removed. (B) Transition of the number of infected.

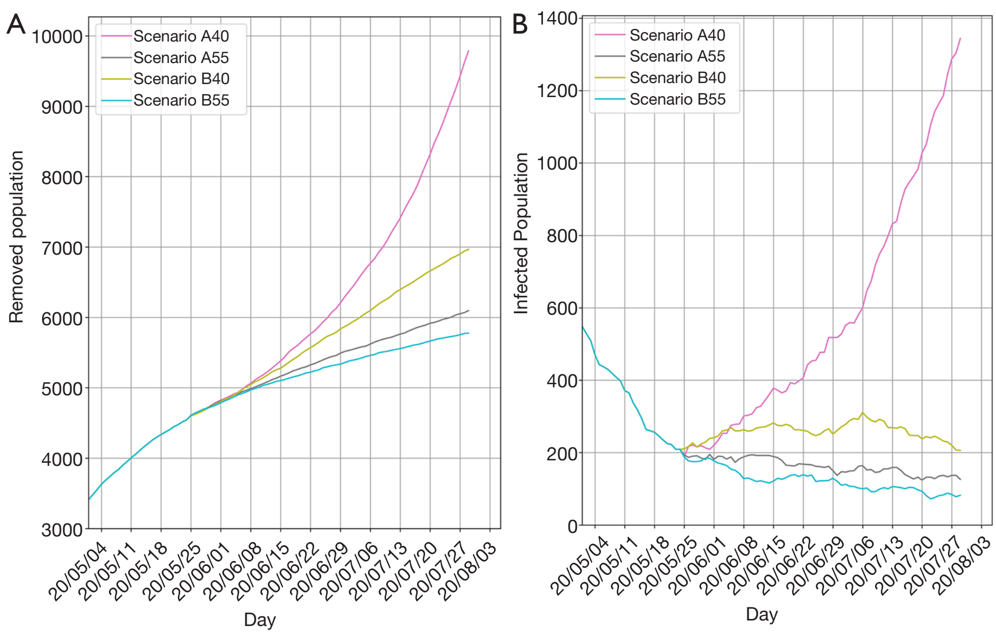

Figure 5 Infection transition in Tokyo predicted in scenarios with different ratio of teleworking by localized stochastic transition model. (A) Transition of the number of removed. (B) Transition of the number of infected.

situation. Indeed, different people behave in different ways and people tend to change their behavior either due to ageing or responding to the environmental signals, such like the declaration of emergency state by the government.

Measures for the early detection of infected people, such as increasing the number of PCR tests (31,32), as well as measures for cluster intervention (33,34), such as isolating those in close contact with detected infected person, have led to the control of infection in Japan within a short period of 49 days. It is argued that the key mechanism of successfully controlling the spread of infection is that the number of segregated per day should exceed the number of infected per day. Simulations proved that this argument is relevant, by the comparison of time evolution of the infected number under a constant removal probability with that under an increasing one.

According to the simulation results, although the first explosive infection of COVID-19 has been avoided in Tokyo, increasing activities in the city again may lead to a second wave of infections. In fact, Tokyo Metropolitan Government (TMG) decided to move to STEP 2 of the "roadmap for overcoming new coronavirus infectious diseases" (35) from June 1. Correspondingly, self-restraint requests for some industries are lifted in order to restore the state of economy (36). From June 12, TMG decided to move to STEP 3 (37), basically lifting self-restraint requests for all industries. The recent data has already shown that the complete resumption of activities is likely to lead to increasing the number of infected people. As implied by Scenarios B and E, it would be desirable to maintain a partial suppression of activities, though the spread of infection could not subside completely. Based on the simulation of Scenarios C and F, only if a large amount of self-restraint were implemented, the complete convergence could be realized, which, however, might cause a too big economic damage in the meantime.

Teleworking may become a way out of the dilemma between the effective suppression of COVID-19 infection and the evasion of a large scale economic recession. Simulations indicate that when 55% of working people aged from 20 to 64 change their working style into telework would end the spread of infection without significant economic damage. According to a survey in April (38), 62.7% of Japanese companies have introduced the telework environment, partly thanks to TMG's support. Also, the survey shows that 49.1% of the employees were doing telework in April. However, this figure seems to be temporary effect of the state of emergency, we are not sure how many people will do telework after June. The behavior pattern used in Scenarios A55 and B55 also suggest to keep the activity to about 75% of the normal activity level. In reality, lowering the activity can be achieved not only by forcefully restricting the human activity, but also by reducing chance of staying in an environment with a high probability of infection.

Conclusions

To summarize, our analysis shows that the major cause for the success of controlling the first outbreak in Tokyo is the early request of self-restraint as well as the early detection of infected people. However, increasing human activities again in the resumption of economy will lead to the second wave of infections. To control the spread of infection while maintaining a certain level of economic activity, it should change the workstyle of 55% of working people to teleworking and to reduce 25% time staying in the high infection risk area, the latter of which can be realized by executing infallibly the policy for avoiding "closed spaces, crowded places, and close-contact settings". All in all, this study suggests that to avoid situations with a high probability of infection and to change the regular working into teleworking should become a new lifestyle in face of COVID-19, especially for Tokyo and other cities that with a high population density.

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Footnote

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at http://dx.doi.org/10.21037/atm-20-5334). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Supplementary

Table S1 Initial population of susceptible, infected, removed in each city

City	Subgroup	Initial population in each city			
		Susceptible	Infected	Removed	Total
Tokyo					
Age					
0–19	Normal	1,889,995	4	1	1,890,000
	Active	210,000	0	0	210,000
20–64	Normal	2,459,909	65	26	2,460,000
	Active	820,000	0	0	820,000
	Complete telework	2,050,000	0	0	2,050,000
	Partial telework	2,870,000	0	0	2,870,000
65~	Normal	2,699,966	24	10	2,700,000
	Active	300,000	0	0	300,000
Total		13,299,870	93	37	13,300,000
Chiba					
Age					
0–19	Normal	989,998	1	1	990,000
	Active	110,000	0	0	110,000
20–64	Normal	1,079,972	17	11	1,080,000
	Active	360,000	0	0	360,000
	Complete telework	900,000	0	0	900,000
	Partial telework	1,260,000	0	0	1,260,000
65~	Normal	1,529,990	6	4	1,530,000
	Active	170,000	0	0	170,000
Total		6,399,960	24	16	6,400,000
Kanagawa					
Age					
0–19	Normal	1,349,998	1	1	1,350,000
	Active	150,000	0	0	150,000
20–64	Normal	1,589,955	27	18	1,590,000
	Active	530,000	0	0	530,000
	Complete telework	1,325,000	0	0	1,325,000
	Partial telework	1,855,000	0	0	1,855,000
65~	Normal	2,069,987	6	7	2,070,000
	Active	230,000	0	0	230,000
Total		9,099,940	34	26	9,100,000
Saitama					
Age					
0–19	Normal	1,080,000	0	0	1,080,000
	Active	120,000	0	0	120,000
20–64	Normal	1,259,993	4	3	1,260,000
	Active	420,000	0	0	420,000
	Complete telework	1,050,000	0	0	1,050,000
	Partial telework	1,470,000	0	0	1,470,000
65~	Normal	1,709,997	2	1	1,710,000
	Active	190,000	0	0	190,000
Total		7,299,990	6	4	7,300,000
Gunma					
Age					
0–19	Normal	270,000	0	0	270,000
	Active	30,000	0	0	30,000
20–64	Normal	300,000	0	0	300,000
	Active	100,000	0	0	100,000
	Complete telework	250,000	0	0	250,000
	Partial telework	350,000	0	0	350,000
65~	Normal	540,000	0	0	540,000
	Active	60,000	0	0	60,000
Total		1,900,000	0	0	1,900,000
Tochigi					
Age					
0–19	Normal	270,000	0	0	270,000
	Active	30,000	0	0	30,000
20–64	Normal	299,997	2	1	300,000
	Active	100,000	0	0	100,000
	Complete telework	250,000	0	0	250,000
	Partial telework	350,000	0	0	350,000
65~	Normal	540,000	0	0	540,000
	Active	60,000	0	0	60,000
Total		1,899,997	2	1	1,900,000
Ibaraki					
Age					
0–19	Normal	450,000	0	0	450,000
	Active	50,000	0	0	50,000
20–64	Normal	480,000	0	0	480,000
	Active	160,000	0	0	160,000
	Complete telework	400,000	0	0	400,000
	Partial telework	560,000	0	0	560,000
65~	Normal	720,000	0	0	720,000
	Active	80,000	0	0	80,000
Total		2,900,000	0	0	2,900,000

Table S2 Behavioral pattern of each group that represents the time spent per day in each zone

Term	Zone	Time staying at each place per day (hour)															
		Age: 20–19				Age: 20–64								Age: 65~			
		Normal		Active		Normal		Active		Complete telework		Partial telework		Normal		Active	
		Weekdays	Holidays	Weekdays	Holidays	Weekdays	Holidays	Weekdays	Holidays	Weekdays	Holidays	Weekdays	Holidays	Weekdays	Holidays	Weekdays	Holidays
03/01–03/19	Crowded	4	4	12	12	10	10	12	12	4	8	10	10	6	6	12	12
	Mid	12	12	6	6	6	6	6	6	12	8	6	6	10	10	6	6
	Uncrowded	8	8	6	6	8	8	6	6	8	8	8	8	8	8	6	6
03/20–04/06	Crowded	5	5	12	12	10	12	12	12	4	10	10	12	7	7	12	12
	Mid	11	11	6	6	6	4	6	6	12	6	6	4	9	9	6	6
	Uncrowded	8	8	6	6	8	8	6	6	8	8	8	8	8	8	6	6
04/07–04/13	Crowded	3	3	10	10	8	4	10	10	4	4	4	4	5	4	10	10
	Mid	13	13	6	6	8	12	6	6	12	12	12	12	11	12	6	6
	Uncrowded	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
04/14–04/20	Crowded	2	2	8	8	5	2	8	8	3	2	3	2	3	3	8	8
	Mid	14	14	8	8	11	14	8	8	13	14	13	14	13	13	8	8
	Uncrowded	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
04/21–04/27	Crowded	1	1	6	6	4	1	6	6	2	1	2	1	2	1	6	6
	Mid	15	15	10	10	12	15	10	10	14	15	14	15	14	15	10	10
	Uncrowded	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
04/28–05/04	Crowded	1	1	6	6	4	1	6	6	2	1	2	1	2	1	6	6
	Mid	15	15	10	10	12	15	10	10	14	15	14	15	14	15	10	10
	Uncrowded	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
05/05–05/24	Crowded	2	2	8	8	5	2	8	8	3	2	3	2	3	3	8	8
	Mid	14	14	8	8	11	14	8	8	13	14	13	14	13	13	8	8
	Uncrowded	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8

Table S3 Percentage of people moving between cities per day

Term	To	Percentage of people moving between cities per day						
		From						
		Tokyo	Chiba	Kanagawa	Saitama	Gunma	Tochigi	Ibaraki
03/01–03/19	Tokyo	–	9.0%	9.0%	9.0%	0.9%	0.9%	0.9%
	Chiba	1.6%	–	3.6%	1.8%	0.9%	0.9%	3.6%
	Kanagawa	1.6%	3.6%	–	1.8%	0.9%	0.9%	0.9%
	Saitama	1.6%	3.6%	3.6%	–	3.6%	3.6%	3.6%
	Gunma	1.6%	0.9%	0.9%	1.8%	–	3.6%	3.6%
	Tochigi	1.6%	0.9%	0.9%	1.8%	3.6%	–	3.6%
	Ibaraki	1.6%	3.6%	0.9%	1.8%	3.6%	3.6%	–
03/20–04/06	Tokyo	–	10.0%	10.0%	10.0%	1.0%	1.0%	1.0%
	Chiba	1.8%	–	4.0%	2.0%	1.0%	1.0%	4.0%
	Kanagawa	1.8%	4.0%	–	2.0%	1.0%	1.0%	1.0%
	Saitama	1.8%	4.0%	4.0%	–	4.0%	4.0%	4.0%
	Gunma	1.8%	1.0%	1.0%	2.0%	–	4.0%	4.0%
	Tochigi	1.8%	1.0%	1.0%	2.0%	4.0%	–	4.0%
	Ibaraki	1.8%	4.0%	1.0%	2.0%	4.0%	4.0%	–
04/07–04/13	Tokyo	–	9.0%	9.0%	9.0%	0.9%	0.9%	0.9%
	Chiba	1.3%	–	3.6%	1.8%	0.9%	0.9%	3.6%
	Kanagawa	1.3%	3.6%	–	1.8%	0.9%	0.9%	0.9%
	Saitama	1.3%	3.6%	3.6%	–	3.6%	3.6%	3.6%
	Gunma	1.3%	0.9%	0.9%	1.8%	–	3.6%	3.6%
	Tochigi	1.3%	0.9%	0.9%	1.8%	3.6%	–	3.6%
	Ibaraki	1.3%	3.6%	0.9%	1.8%	3.6%	3.6%	–
04/14–04/20	Tokyo	–	6.0%	6.0%	6.0%	0.6%	0.6%	0.6%
	Chiba	1.0%	–	2.4%	1.2%	0.6%	0.6%	2.4%
	Kanagawa	1.0%	2.4%	–	1.2%	0.6%	0.6%	0.6%
	Saitama	1.0%	2.4%	2.4%	–	2.4%	2.4%	2.4%
	Gunma	1.0%	0.6%	0.6%	1.2%	–	2.4%	2.4%
	Tochigi	1.0%	0.6%	0.6%	1.2%	2.4%	–	2.4%
	Ibaraki	1.0%	2.4%	0.6%	1.2%	2.4%	2.4%	–
04/21–04/27	Tokyo	–	6.0%	6.0%	6.0%	0.6%	0.6%	0.6%
	Chiba	0.8%	–	2.4%	1.2%	0.6%	0.6%	2.4%
	Kanagawa	0.8%	2.4%	–	1.2%	0.6%	0.6%	0.6%
	Saitama	0.8%	2.4%	2.4%	–	2.4%	2.4%	2.4%
	Gunma	0.8%	0.6%	0.6%	1.2%	–	2.4%	2.4%
	Tochigi	0.8%	0.6%	0.6%	1.2%	2.4%	–	2.4%
	Ibaraki	0.8%	2.4%	0.6%	1.2%	2.4%	2.4%	–
04/28–05/04	Tokyo	–	6.0%	6.0%	6.0%	0.6%	0.6%	0.6%
	Chiba	0.8%	–	2.4%	1.2%	0.6%	0.6%	2.4%
	Kanagawa	0.8%	2.4%	–	1.2%	0.6%	0.6%	0.6%
	Saitama	0.8%	2.4%	2.4%	–	2.4%	2.4%	2.4%
	Gunma	0.8%	0.6%	0.6%	1.2%	–	2.4%	2.4%
	Tochigi	0.8%	0.6%	0.6%	1.2%	2.4%	–	2.4%
	Ibaraki	0.8%	2.4%	0.6%	1.2%	2.4%	2.4%	–
05/05–05/24	Tokyo	–	7.0%	7.0%	7.0%	0.7%	0.7%	0.7%
	Chiba	0.8%	–	2.8%	1.4%	0.7%	0.7%	2.8%
	Kanagawa	0.8%	2.8%	–	1.4%	0.7%	0.7%	0.7%
	Saitama	0.8%	2.8%	2.8%	–	2.8%	2.8%	2.8%
	Gunma	0.8%	0.7%	0.7%	1.4%	–	2.8%	2.8%
	Tochigi	0.8%	0.7%	0.7%	1.4%	2.8%	–	2.8%
	Ibaraki	0.8%	2.8%	0.7%	1.4%	2.8%	2.8%	–
05/25–07/31	Tokyo	–	9.0%	9.0%	9.0%	0.9%	0.9%	0.9%
	Chiba	1.6%	–	3.6%	1.8%	0.9%	0.9%	3.6%
	Kanagawa	1.6%	3.6%	–	1.8%	0.9%	0.9%	0.9%
	Saitama	1.6%	3.6%	3.6%	–	3.6%	3.6%	3.6%
	Gunma	1.6%	0.9%	0.9%	1.8%	–	3.6%	3.6%
	Tochigi	1.6%	0.9%	0.9%	1.8%	3.6%	–	3.6%
	Ibaraki	1.6%	3.6%	0.9%	1.8%	3.6%	3.6%	–

Table S4 Baseline removal probability β_{term} used for each term and pattern

Term	β_{term}	
	Increasing $P_{Removed}$	Constant $P_{Removed}$
03/01–03/19	10.0%	10.0%
03/20–04/06	10.0%	10.0%
04/07–04/13	10.0%	10.0%
04/14–04/20	12.0%	10.0%
04/21–04/27	12.0%	10.0%
04/28–05/04	14.0%	10.0%
05/05–05/24	14.0%	10.0%