Mathematical Model Considering Effect of COVID-19 Contact-Confirming Application (COCOA) and “GoTo Travel Campaign”

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Abstract. In the end of 2019, the emergence of COVID-19 was reported and confirmed for the first time, and it triggered an international pandemic. In Japan, the strong tendency to spread of infection is still continuing. The Japanese Government has been raised two concepts to overcome this difficulty. One is the thorough measures to control of the spread of infection and the other is the economic recovery. The government has carried out the corresponding two policies: the use of COVID-19 Contact-Confirming Application (COCOA) and the application of “GoTo Travel Campaign”. We focus on these two policies and study an ideal situation, which enables us to balance more economic recovery and control of the spread of infection. To pursue this goal, we propose a mathematical model to estimate these policies’s effects and conduct simulations of 28 scenarios. In addition, we analyze each result of the simulation and investigate characteristics of each situation. As a result, we clearly find that it required that not only the increasing the using rate of COCOA but also a positive change of people’s behaviors and awareness.

1. Introduction
Coronavirus disease (COVID-19) has been continuing to spread the infection around the world since it was in the end of 2019, when COVID-19 was confirmed for the first time. In Japan, as of September 2, 2021, the number of the total infectors had been 1,507,223 and the number of the total dead person of COVID-19 had been 16,123 [1].

To overcome this unprecedented difficulty, the COVID-19 Contact-Confirming Application (COCOA) [2] was developed and released by the Japanese government on June 19, 2020. COCOA is an application on a smartphone, which informs the user whether user had come into contact with infectors, for more than 15-minutes less than 1 meter and in the past 14-days, using the function of Bluetooth on the smartphone. However, it is only when both an infector and the person contacted with the infector use COCOA. Then, if a user who received notification about the fact of contact with an infector conducts self-isolation completely, the user can contribute to control of the further spread of infection. From these facts, to decrease
the number of infectors, it is necessary to increase the number of people using COCOA. As of
November, 2020, the user rate of COCOA is about 15% [3]. Omae et al. [4] reported that such
a user rate cannot bring us about the control of the spread of infection. It is necessary for us to
consider the measures to widespread COCOA. The usage rate of COCOA, at present, has been
making little progress among young people, while most of them has been using smartphones in
Japan. If we improve young people’s interest in COCOA and give them the correct information
which removes their misunderstandings of COCOA, they will be positive about installation
of COCOA. Then, we performed a questionnaire survey summarized in Appendix A. It was
suggested that the possibility that keeping everybody informed about the proper information of
COCOA has an effect on improving the usage rate of COCOA.

The Japanese Government has been raised two concepts. One is the thorough measures to
control of the spread of infection and the other is the economic recovery. The government has
carried out the corresponding two policies: the use of COCOA and the application of “GoTo
Travel Campaign”. “GoTo Travel Campaign” is an economic policy. This policy intends to
revitalize the domestic economy which is stagnant because of the regulations spring from the
spread of infection in Japan. When the domestic tourists use “GoTo Travel Campaign”, some
services at places for sightseeing, such as discounting of the price and getting a coupon ticket etc.,
can be received. Thus, this policy enables them to promote consumption. There are various
opinions of this campaign. At the aspect of restoring economy, the policy gains the positive
results. On the other hand, because of this policy, it makes more people go out. Then, this
policy has a possibility of the spread of infection.

There are few simulation researches of country specific simulations on spreading COVID-19
infection [5, 6, 7], the simulations for verifying effect of COVID-19 vaccine [8, 9] and airport
quarantine [10]. Moreover, there are the simulations for verifying to effect of the contact tracing
application such as COCOA [11, 12, 13]. However, at present, the simulations to verify the effect
of combination of COCOA and “GoTo travel campaign” on reducing infected individuals are
insufficient. The simulation approach based on mathematical models is effective to understand
the effect of COCOA in “GoTo travel campaign” on reducing infected individuals. Therefore,
we develop a mathematical model which can investigate the influence of COCOA and “GoTo
Travel Campaign”. Then, we conduct some simulations based on our developed model. To
study an ideal situation, which enables us to balance more economic recovery and control of the
spread of infection, we analyze each result of the simulation and investigate characteristics of
each situation.

2. Model
We summarize the parameters which we use our model in Table 1.

We define $I$ as the number of infectors who has been produced by using “GoTo travel
campaign”. This means the number of infectors by using “GoTo travel campaign” who has been
clarified their own infection by their positive result of the Reverse Transcription Polymerase
Chain Reaction (RT-PCR) test for COVID-19. However, there are infectors who are unaware
of infection. Hence, we assume that the number of infectors who are unaware of infection is $C$
times as many as infectors who have been aware of their own infection. Then, we calculate the
total number of infectors as $IC$.

We use $p_1$ as the usage rate of application for people who accept “GoTo travel campaign”
users i.e., they are original infectors who infect “GoTo travel campaign” users with COVID-19.
We use $p_2$ as the usage rate of application for people who use “GoTo travel campaign” i.e., they
are newly infected people. Then, in the case that both people of the root of infection and people
received the infection used COCOA, the number of new infections can be written by $p_1p_2IC$.

In this situation, if original infectors register the positive result by PCR test to COCOA,
new infectors can receive the contact notification. However, some of original infectors who use
Table 1. Definition of parameters.

| Parameters | Description |
|------------|-------------|
| I          | Total number of infectors produced by using “GoTo travel campaign” |
| C          | Non-finding coefficient |
| R          | Effective reproduction number of COVID-19 |
| p₁         | Original infectors’ usage rate of COCOA |
| p₂         | New infectors’ usage rate of COCOA |
| p₃         | Original infectors’ rate of undergoing RT-PCR test |
| p₄         | Original infectors’ false negative rate of RT-PCR test |
| p₅         | Original infectors’ rate of registration of a COVID-19 positive result |
| p₆         | Rate of self-quarantine of individuals who received the contact notification from COCOA |

COCOA do not perform the RT-PCR test, because they reluctant to reveal their own infection or they are not unaware of own infection. Therefore, not all of infected users might register their own infection. Besides this fact, there is also case that an infector who performs RT-PCR test receives the false negative result. In this case, the original infector who received the RT-PCR test cannot aware of their own infection. They cannot also register their own infection with COCOA. In order to consider these cases, we adopt $p₃$ as the rate of RT-PCR test for people who infect the other person and $p₄$ as the false negative rate of RT-PCR test, in this study. Therefore, the rate of original infectors’ undergoing the RT-PCR test and receiving the positive result of RT-PCR test correctly is $p₃(1 - p₄)$.

In addition to the above fact, some people who notice their own infection refuse the registration in COCOA about their own infection due to having fears of been exposed the fact they are infectors. To express this phenomenon, we adopt $p₅$ as the rate of registration of a COVID-19 positive result.

Not all people who received the contact notification from COCOA thorough the self-isolation because of the various reasons. They might be the factor of the spread of infection. To consider this case, we adopt $p₆$ as the rate of self-quarantine of individuals who received the contact notification from COCOA.

Therefore, the total number of people who contribute to controlling the spread of infection through COCOA contact notification is $PIC$, where $P = p₁p₂p₃(1 - p₄)p₅p₆$, which means the probability of the simultaneous occurrence of all the above mentioned events.

We consider how many newly infected people can prevent their infection beforehand by the action of original infector. In the field of infectious disease epidemiology, the total number of infections transmitted by one infected person to others during the entire period of infection is called the effective reproduction number [14]. In this study, we use $R$ as the effective reproduction number of COVID-19. Naturally, we can consider $PIC$ infected people might infect $PICR$ people with COVID-19 during the entire period of infection. However, thanks to thoroughly conduct self-isolation by $PIC$ infectors, $PICR$ people end up uninfected. On the other hand, the true number of reduced infectors does not remain $PICR$ people. The reason is that $PICR$ people also prevent new $PICR²$ people who should have been infected by that $PICR$ people from infecting. In other words, the number of infectors who were reduced per a certain unit of time will increase as time rolls on. We adopt $t$ as unit of time to investigate this tendency.

When the number of infectors who were reduced per a certain unit of time consider as $dₜ$, we can estimate the total number of infected people on $t = 1$ as $d₁ = PICR$. In the same manner,
when \( t = 2 \) and \( t = 3, \ldots \), the number of infectors who were reduced per a certain unit of time can be estimated as the following equations:

\[
\begin{align*}
    d_2 &= PIC(R + R^2), \\
    d_3 &= PIC(R + R^2 + R^3), \\
    &\vdots
\end{align*}
\]

Therefore, we obtain:

\[
    d_t = PIC(R + R^2 + \cdots + R^t).
\]

Here, \( R + R^2 + \cdots + R^t \) is the sum from the first term \( R \) to the \( t \)-th term of the geometric progression with common ratio \( R \). Then, Eq.(3) can be expressed:

\[
    d_t = PIC \frac{R(R^t - 1)}{R - 1}.
\]

Besides, an infected person at \( t \) will produce another infected person at \( t + 1 \). However, this person will not produce another infected person after \( t + 2 \). If the unit time of \( t \) is the duration of infection, this person is already cured at \( t + 1 \).

3. Simulation

3.1. Outline

We conduct the simulation using our developed mathematical model to investigate the reducing effect in the both cases i.e., COCOA as a measure to control the infection and “GoTo travel campaign” as a policy to recovery economic activity.

In this simulation, it is necessary to decide the value of parameters: \( p_1, p_2, p_3, p_4, p_5, p_6, I, C \) and \( R \) summarized in Table 1.

We mention \( I \), which means the number of noticed infectors who has been produced by using “GoTo travel campaign”. From September to October in 2020, the period when “GoTo travel campaign” conducted, the average number of domestic tourists for a month was about 28.58 million [15]. Although it is not obvious whether all of them used “GoTo travel campaign”, we assume all of them used it as pessimistic value, because the concrete rate of it is obscure. Here, there is a report that says they are infected one in 270 thousand people [16]. The rate of infectors was noticed their own infections by receiving RT-PCR test. Thus, the number of noticed infectors who has been produced by using of “GoTo travel campaign” can be calculated: \( I \sim 106 \).

However, this is the number of infections detected by the PCR test. Thus, the number of non-detected infections should also be taken into account. In the study that considered how many times more infected people were lurking in the background than those detected, Tsuchiya [14] estimated about 23 times more. Since this is not a study of the period of “GoTo travel campaign”, it might be not desirable to estimate that the total number of infected persons is more 23 times than that of the number of cases detected. However, since the estimate for other periods has not been made sufficiently, in this study, we assume \( C = 23 \) as the coefficient of undetected cases.

In this study, we adopt \( R = 1.10 \), because the domestic effective reproduction number from late September to early October, 2020 was about 1.10 [17].

We mention unit of time \( t \). \( t \) is defined as the incubation period of COVID-19. The duration of COVID-19 infection is assumed to be 14 days [18]. Thus, we use \( t = 14 \) days.

In addition, we describe the usage rate of COCOA \( p_1, p_2 \). As of November 17, 2020, the usage rate of COCOA was around 15% [3]. Thus, we adopt \( p_1, p_2 = 0.15 \) and \( p_1, p_2 = 0.50, 1.00 \) to investigate the case of succeeding in spreading of using COCOA as well.
### Table 2. Effectiveness of reducing the number of infectors for 28 scenarios.

| ID | $I$ | $C$ | $R$ | $p_1$ | $p_2$ | $p_3$ | $p_4$ | $p_5$ | $p_6$ | $d_{t=6}$ |
|----|----|----|----|------|------|------|------|------|------|---------|
| S1 | 106 | 23 | 1.10 | 0.00 | 0.00 | 0.00 | 0.38 | 0.30 | 1.00 | 0.00 |
| S2 | 106 | 23 | 1.10 | 0.15 | 0.15 | 0.15 | 0.38 | 0.30 | 1.00 | 8.66 |
| S3 | 106 | 23 | 1.10 | 0.15 | 0.15 | 0.10 | 0.38 | 0.30 | 1.00 | 28.86 |
| S4 | 106 | 23 | 1.10 | 0.15 | 0.50 | 0.10 | 0.38 | 0.30 | 1.00 | 57.73 |
| S5 | 106 | 23 | 1.10 | 0.15 | 0.50 | 0.10 | 0.38 | 0.30 | 1.00 | 28.86 |
| S6 | 106 | 23 | 1.10 | 0.50 | 0.50 | 0.10 | 0.38 | 0.30 | 1.00 | 96.23 |
| S7 | 106 | 23 | 1.10 | 0.50 | 0.50 | 0.10 | 0.38 | 0.30 | 1.00 | 192.43 |
| S8 | 106 | 23 | 1.10 | 1.00 | 0.10 | 0.38 | 0.30 | 1.00 | 57.73 |
| S9 | 106 | 23 | 1.10 | 1.00 | 0.30 | 0.30 | 0.30 | 1.00 | 192.43 |
| S10 | 106 | 23 | 1.10 | 1.00 | 1.00 | 0.30 | 0.30 | 1.00 | 384.87 |
| S11 | 106 | 23 | 1.10 | 0.15 | 0.15 | 0.50 | 0.38 | 0.30 | 1.00 | 43.30 |
| S12 | 106 | 23 | 1.10 | 0.15 | 0.50 | 0.50 | 0.38 | 0.30 | 1.00 | 144.32 |
| S13 | 106 | 23 | 1.10 | 0.15 | 1.00 | 0.50 | 0.38 | 0.30 | 1.00 | 288.65 |
| S14 | 106 | 23 | 1.10 | 0.50 | 0.15 | 0.50 | 0.38 | 0.30 | 1.00 | 481.08 |
| S15 | 106 | 23 | 1.10 | 0.50 | 0.50 | 0.50 | 0.38 | 0.30 | 1.00 | 962.17 |
| S16 | 106 | 23 | 1.10 | 0.50 | 1.00 | 0.50 | 0.38 | 0.30 | 1.00 | 1924.33 |
| S17 | 106 | 23 | 1.10 | 1.00 | 0.15 | 0.50 | 0.38 | 0.30 | 1.00 | 577.30 |
| S18 | 106 | 23 | 1.10 | 1.00 | 0.50 | 0.50 | 0.38 | 0.30 | 1.00 | 1924.33 |
| S19 | 106 | 23 | 1.10 | 1.00 | 1.00 | 0.50 | 0.38 | 0.30 | 1.00 | 3848.66 |

*Definition of parameters can be seen in Table 1.

Similarly, we adopt the rate of undergoing RT-PCR test for people who infect the other person, as $p_3 = 0.15, 0.50, 1.00$, respectively. For the false negative rate of RT-PCR test $p_4$, Kuciruka et al. [19] reported $p_4 = 0.38$ as the median of COVID-19’s the false negative rate of RT-PCR test. Thus, we put this value as $p_4$.

Because there is no sufficient knowledge right now of both the rate of registration of COVID-19’s positive result $p_5$ and the rate of self-quarantine of individuals who the contact notification from COCOA $p_6$, we use $p_5 = 0.30$ and $p_6 = 1.00$, respectively, as subjective value.

We summarize the scenario which we investigate in Table 2.

### 3.2. Results and Discussion

The results of reducing the number of infectors of 28 scenarios at $t = 6$ ($6 \times 14 = 84$ elapsed days) are shown in Table 2.

First of all, according to Scenario S1, the effect of reducing the number of infected people is
Figure 1. Reduced number of infectors of S11, S15, and S19 as the function of unit time. Scenario’s difference is usage rate of COCOA $p_1$ and $p_2$.

Figure 2. Reduced number of infectors of S6, S15, and S24 as the function of unit time. Scenario’s difference is the rate of undergoing RT-PCR test $p_3$.

not expected in case when COCOA does not exist.

We can also confirm that in the case of the low usage rate of COCOA of both the side of accepting “GoTo travel campaign” and the side of using “GoTo travel campaign” ($p_1$, $p_2 = 0.15$, i.e., Scenarios S2, S11, S20), the reduction effect is small. This means that since $p_1$, $p_2 = 0.15$ is same as the usage rate in about November, 2020, the effect of reducing the number of infected people by COCOA was not sufficient in Japan. $d_t$ of S11, S15, and S19 are shown in Fig. 1 for verification of the impact of the usage rate of COCOA $p_1$ and $p_2$. $p_1$ and $p_2$ of S11, S15, and S19 are 0.15, 0.50 and 1.00, respectively. Figure 1 indicates that when the usage rate of COCOA $p_1$, $p_2$ is high, more effect of reducing the number of infected people $d_t$ grows up. Therefore, the usage rates of the COCOA are important parameters to decrease infectors.

Moreover, the rate of undergoing PCR test might be also important parameter. For example, S10, S19, S28 are the scenarios in which the rate of undergoing RT-PCR test $p_3$ is adopted 0.10, 0.50, 1.00, respectively. In this case, turning attention to effect of reducing the number of infected people, we can confirm a significant increase of $d_t$ as the value of $p_3$ grow up. Especially S28 means that the case we can succeed in expanding RT-PCR test. In this case, the number of the positive person found by PCR test in entire society may increases so that people who can register their own infection to COCOA may increase. This means that effect of reducing the number of infected people enhances because it means that the number of people who receive contact notification increases.
To check the time-dependence effects of the undergoing rate of PCR test, the results of S6, S15 and S24 (which are $p_3 = 0.10, 0.50, 1.00$, respectively) are shown in Fig. 2. Figure 2 indicates the reduction effects increase as time elapsed in the case of high value of $p_3$. Therefore, we concluded that the rate of undergoing PCR test $p_3$ is one of the important parameters.

Note that, in this study, we fix some parameters, e.g., the false negative rate of RT-PCR test $p_4 = 0.38$ and the rate of self-quarantine of individuals who received the contact notification from COCOA $p_6 = 1.00$. Although we cannot discuss these effects from the result, we find these two also have an great influence of the effect of reducing the number of the infected people from Eq.(4). Therefore, the development of inspection skill like decreasing the false negative rate of RT-PCR test $p_4$, and/or the enlightenment movement such as increasing the rate of self-quarantine of individuals who received the contact notification from COCOA $p_6$, are also important to enhance the effect of reducing the number of infected people by COCOA.

Summing up these arguments, when we conduct a commitment using COCOA to whole society, it will be obvious that it is important to use correctly with their own awareness against controlling the spread of infection and to conduct activities which call for COCOA use by government or local government thoroughly.

4. Summary
In this study, to make it compatible with the prevention of infection spread and the revitalization of economic activity, we performed the simulation of 28 scenarios combined with COCOA and “GoTo travel campaign”. As a result, it was confirmed that not only the usage rate of COCOA but also other conditions such as the rate of performing RT-PCR test had a big influence on effect of reducing the number of infected people. That is to say, it is important for people who use “GoTo travel campaign” to use COCOA actively, to promote self-management awareness and to change their actions spontaneously.

As our future works, we will analyze more in detail, adding various conditions to the scenarios which we verified this time. At the same time, it is important to examine how environment can perform behavior change which can reduce more infected people by COCOA and how measure is effective so that we produce it.

Here, we discuss the limitations of our model. Our mathematical model can apply only when the effective reproduction number $R$ is not depending on the time. In reality, the effective reproduction number $R$ is situational dependence (whether or not state of emergency is declared, etc.) so that it is desirable to simulate only the period when fluctuation in $R$ is little. Because this model does not reflect the number of susceptible person (a person who is susceptible to the virus), we note that it should be applied only when it is sufficiently large compared with $d_t$.

Moreover, each event which is associated with $P$ (using the application, performing RT-PCR test, etc.) may not be independent of each other. However, calculating $P$ as a concrete number is so difficult that it is important to note that they are supposed to be independent. For instance, though the application users tend to be easier to perform RT-PCR test, it seems that quantitative data on the degree to which people are likely to perform did not report sufficiently.

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Appendix A. Questionnaire survey about the spread of COCOA
We performed a questionnaire survey about the spread of COCOA on December, 2020. We did not report the result elsewhere. We briefly summarize it in this appendix.
We surveyed 128 students at a high school, Japan on recognition of the correct knowledge of COCOA and whether COCOA was installed or not.

As a result of questionnaire survey, the installation rate of COCOA was 10% of the target-students. As the reason that they did not install and use COCOA, most people answered: “it seems to be charged for communication” and “They are worried about the treatment of the private information”.

After the questionnaire survey, we gave the students who did not install COCOA the following information. “COCOA is an application which the Ministry of Health Labor and Welfare in Japan releases to prevent the spread of the infection. It senses contact with a positive person through Bluetooth and informs that. This application is effective through the use of more people. When we use the application, the communication fee does not arise by using Bluetooth. The device’s information becomes an encrypted signal and used to detect contact so that we cannot identify an individual and/or know where we met. When we use COCOA in the smart-phone model most people now have, the power consumption is considerably less”.

After this procedure, we asked again them if they wanted to install the application from now on. As the result, one-third of them answered: “want to install COCOA”. Therefore, we guess that spreading the correct information of COCOA is considered to have a certain effect on improving the usage rate of application.

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