Assessment of the Impact of COVID-19 Infections Considering Risk of Infected People Inflow to the Region

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Agenda

- Introduction
- Impact on inflows of infected people in tourist areas, Sapporo city
- Infection prevention of the metropolitan, Tokyo
- Predicting the effectiveness of vaccination
- Predicting the effectiveness of vaccination for new variant coronavirus
- Discussion
- Related work
- Conclusion
Introduction

• The Go To Travel campaign was launched in July 2020
• The second wave of the new coronavirus outbreak was beginning to take hold.
• In order to ensure "safe and secure travel", various infection control measures had to be observed.

The "three Cs"

At the heart of the Japanese government’s public health approach to controlling the spread of the virus are the "three Cs", identifying conditions under which the virus is at the greatest risk of spreading and that should be avoided:

• **closed spaces** with poor ventilation
• **crowded places** with many people nearby
• **close-contact situations** such as up-close conversations
Infection spreads in Hokkaido

- Between October and December 2020, a rapid spread of the infection occurred in Hokkaido.

- As a result, the Hokkaido government declared its own state of emergency.
Mobile spatial statistics

- Mobile spatial statistics data using GPS are used to estimate the risk of inflows of infected people moving across prefectures.

\[
in\_risk_{j,t} = \sum_{i=1, i \neq j}^{47} \frac{\sum_{k=1}^{14} cp_{i,t-k} \cdot flow_{i,j,t-k}}{pop_i}
\]

cp: influx of infected people
We adopted a SEIR model that includes the incubation period. In regional cities, including tourist spots, the spread of infection may be accelerated by the inflow of people from the Tokyo, etc. Therefore, we developed the SEIR model taking into account the risk of inflows.

\[
\frac{dS}{dt} = mN - mS - b\frac{S(I + \text{in\_risk})}{N}
\]
\[
\frac{dE}{dt} = b\frac{S(I + \text{in\_risk})}{N} - (m + a)E
\]
\[
\frac{dI}{dt} = aE - (m + g)I
\]
\[
\frac{dR}{dt} = gI - mR
\]
Impact on inflows of infected people in tourist areas, Sapporo city

Estimation of the inflow risk for long-distance travel
Sapporo model

• The right figure shows the time series data of the inflow risk.
• The data were calculated according to the tourism statistics in Hokkaido and mobile spatial statistics in whole regions Japan.
• The blue bars show the number of new cases in Hokkaido between March and December last year.
• The orange line shows the inflow risk that the estimated number of infected people coming from other regions for tourism or business.

Risk of inflows of infected persons
(LocationMind xPop ©LocationMind Inc.)
Estimated number of infected people in Sapporo using Data assimilation

- The black solid line is the actual number of newly infected persons.
- The solid red line is the number of infected persons estimated by SEIR from the effective reproduction number (dotted yellow line).
- The blue dotted line is the estimated risk of influx from other regions.
- The dashed green line is an estimate based on data assimilation using a particle filter.
Estimated number of infected people in Sapporo
Estimated from effective reproduction numbers

• The effective reproduction number is an observed value of the phenomenon caused by people's actions, and we do not want to modify it at will.

• We assume that the relationship between the infection rate $b$ and the effective reproduction number $R_t$ is constant during the period under study.
Estimated number of infected people in Sapporo
Estimated impact of reduced risk of influx

- An increase in the inflow risk seems to have a cumulative effect on the spread of infection over several months (A).

- The simulation results shows that the inflow risk of 0.5 times since July would have reduced the number of infected people in November by 0.68 times (B1); 0.2 times would have reduced the number of infected people by 0.47 times (B2).
Infection prevention measures of the metropolitan area, Tokyo

Estimating the effectiveness of infection control measures under a declared state of emergency
The declaration of a state of emergency in Tokyo

• In the metropolitan area, including Tokyo, the number of infections increased rapidly from December 2020.

• In this context, the main infection prevention measures called for by the government include closing restaurants at 20:00, strengthening telework and limiting large-scale events.

• Mathematical models of infectious diseases, however, are unable to explicitly estimate the effect of such preventive measures.
Individual base model for urban areas around Tokyo

- SEIR model is suitable for prediction, but it is difficult to model the effect of specific infection control measures.

- The model is based on the household structure of a suburb of Tokyo and is represented by 1348 agents in two cities.

<table>
<thead>
<tr>
<th>Household</th>
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<tbody>
<tr>
<td>Elderly single</td>
<td>18</td>
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<td>12</td>
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</tbody>
</table>
Comparison of the infection prevention measures in the emergency declaration

The main infection prevention measures called for in the emergency declaration

- Shorter hours in restaurants
- Enhanced teleworking
- Limiting the number of people up to 5,000 at large events and 50% of the seats at other events

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<td>Restaurants close at 20:00</td>
<td>visitors by 1/2</td>
</tr>
<tr>
<td>Restaurants close at 18:00</td>
<td>visitors by 1/4</td>
</tr>
<tr>
<td>Teleworking 50%</td>
<td>reduce attendance by 50%</td>
</tr>
<tr>
<td>Teleworking 70%</td>
<td>reduce attendance by 30%</td>
</tr>
<tr>
<td>Restrictions on large scale events</td>
<td>Venue restrictions</td>
</tr>
</tbody>
</table>
Effectiveness of infection prevention measures

The usual under-four policy
SEIR Inverse Simulation Model

- SEIR model taking into account population flow data in Tokyo

\[ \text{flow}_t = \frac{\sum_j \text{flow}_{i,t} \times cp_t \times ur}{\text{pop}} \]

cp: number of infected people
ur: smartphone usage rate

- An optimization method combining an evolutionary search algorithm and a quasi-Newton method

\[
b_{\text{elder}} = R_{t,\text{elder}} x_{1,\text{elder}} - x_{2,\text{elder}} \]
\[
b_{\text{adult}} = R_{t,\text{adult}} x_{1,\text{adult}} - x_{2,\text{adult}} \]

\[
\text{minimize} \sum_{t=1} \left( \text{pred}_t(R_{t,\text{elder}}, R_{t,\text{adult}}, x_{1,\text{elder}}, x_{2,\text{elder}}, x_{1,\text{adult}}, x_{2,\text{adult}}, \text{inter rate}) - \text{observ}_t \right)^2
\]

subject to
\[
x_{\text{elder}} \geq 0
\]
\[
x_{\text{adult}} \geq 0
\]
\[
1 \geq \text{inter rate} \geq 0
\]
Estimation of the number of people infected by infection prevention measures

• Using the effective reproduction number of infection control measures estimated by the IBM, the SEIR model estimated the number of people infected under a declared state of emergency.

• Observed number of infected people is black line.

• Estimated number of infected people is blue dotted line.
Estimation of the number of people infected by infection prevention measures

- When basic measures are taken alone, a sharp increase in the number of infected people (red)
- The number of customers using restaurants is restricted to 50% (purple)
- Teleworking is increased to 50% of the workforce (brown)
- Slanted seating and shielding plates to prevent splashes at a table (green)
- The number of customers using restaurants was restricted to 25% (pink)
- Comprehensive prevention measures are implemented (light blue)
Comparison of the estimated number of infected people with the observed number of subsequently infected people

Left: estimates, right: observations in February
Predicting the effectiveness of vaccination

In this model, we simulate when Tokyo residents have the same behavior (≈ effective reproduction number) as after June 1 last year.
Estimated effect of vaccination after March

- The number of infected people in Tokyo is modelled by age group (60+ and under 59) to predict the effect of vaccination for each age group.
- Predicted value without vaccination when the number of infected people is 200 on 21 March.
- Total number of infected people (red dashed line)
- The next wave, which is forth in Japan, would come and peak at 1,550 cases in May.

Estimated number of infected people after the emergency declaration is lifted

In the case that Tokyo residents have the same behavior (≈ effective reproduction number) as after June 1 last year.
Estimated effect of vaccination after March

- Predicted value if vaccine was given at a dose of 0.3% of the population per day, with priority given to the elderly.
- The next wave would come and peak with 1,500 cases in May.
Estimated effect of vaccination after March

- Predicted value if vaccine was given at a dose of 0.5% of the population per day, with priority given to the elderly.
- The next wave would come and peak at 1,470 cases in May.
- The fifth wave would be prevented by vaccination.

Estimated number of infected people after the emergency declaration is lifted

Vaccination is given to 0.5%/day with priority given to the elderly
Estimated effect of vaccination after March

- Predicted value if vaccine was given at a dose of 0.5% of the population per day, with priority given to the elderly and adopting the usual under-four policy.
- The fourth wave would come and peak at 340 cases in May and the fifth wave would not come.

Estimated number of infected people after the emergency declaration is lifted

Vaccination is given to 0.5%/day with priority to the elderly, and "no more than four people going out, and diagonal seating and shielding boards for dinners"
Predicting the effectiveness of vaccination for new variant coronavirus

In this model, we simulate when Tokyo residents have the same behavior (≈ effective reproduction number) as after June 1 last year.
Estimated effect of vaccination for new variant of B.1.1.7 (England type) with 0.3%/d vaccine

- Predicted value with vaccination of 0.3%/day with priority to the elderly when people infected by new variant virus of B.1.1.7 is 10 on 21 March.
- New variant virus (yellow dashed line)
- The fifth wave would rise sharply in autumn and peak at 5640 cases.

Estimated number of infected people after the emergency declaration is lifted

Vaccination is given to 0.3%/day with priority to the elderly
Estimated effect of vaccination for new variant of B.1.1.7 (England type) with 0.5%/d vaccine

• Predicted value with vaccination of 0.5%/day priority to the elderly when the number of people infected by new variant virus of B.1.1.7 is 10 on 21 March.
• New variant virus (yellow dashed line)
• The fifth wave would not come.

Estimated number of infected people after the emergency declaration is lifted

Vaccination is given to 0.5%/day with priority to the elderly
Estimated effect of vaccination for new variant of 501.V2 (South Africa type) with 0.5%/d vaccine

- Predicted value with vaccination of 0.5%/day priority to the elderly when the number of people infected by new variant virus of 501.V2 is 10 on 21 March.
- New variant virus (yellow dashed line)
- The fifth wave would rise sharply in autumn and peak at over 9000 cases.

Vaccination is given to 0.5%/day with priority to the elderly
Discussion : Inflow risk and fitting

• In this model, the estimation accuracy was improved by using mobile spatial statistics data and inverse simulation optimization with evolutionary computation. Since the model takes into account the risk of inflow of infected people from other areas.

• We think that the model is expected to have a reasonable abstraction of the phenomenon and a reasonable prediction accuracy for events different from the observed data. Thus, we believe that excessive fitting should be avoided to understand phenomenon and predict future.
Discussion : Prevention measures in Sapporo

- When the number of infected people in the city is low, little infection explosion occurs.

- The model shows concretely the extent to which the increase in cross-border migration from summer had an impact on the spread of infection a few months later.

- If the number of people coming from other prefectures could be limited to 80%, the results show that the number of infected people could be reduced up to half.
Discussion: Total prevention measures in Tokyo

- In the Tokyo model using an individual-based model, it was able to estimate the effect of prevention measures in more detail, rather than simply estimating a "percentage reduction" in the infection rate.

- Using these estimates, we estimated the effect of the total prevention measures, including the use of slanted seating and shielding boards, the strengthening of teleworking, and the restriction of large-scale events, are highly effective. The actual number of infected people in the following months showed almost the same trend.

- The combination of IBM/ABM and mathematical modelling (SIR, etc.) has been shown to be effective.
Discussion: Vaccination effect

• It is predicted that the next wave would peak in May, if people become more active after the state of emergency was lifted.

• Estimates of the effectiveness of vaccination showed that the vaccine was powerless against the fourth wave in May. On the other hand, the vaccine was shown to be effective against the fifth wave from October onwards.

• In this case, however, a vaccination dose of 0.5%/day of population is required.
Discussion : New variant risk

• The results of predicting the number of people infected with the England variant in Tokyo showed that if there were 10 people infected with the variant of the virus on 21 March, vaccination at 0.3%/day would not prevent the spread of the fifth wave of infection, while vaccination at 0.5%/day would prevent the spread of infection.

• Prediction with the South African variant, however, showed that vaccination even at 0.5%/day would not prevent the fifth wave of infection.
Related work

• Impact of non-pharmaceutical interventions (NPIs) to reduce COVID-19 mortality and healthcare demand
  Neil M Ferguson et al. (ICL, 16 March)
  ABM + Regression model

• Inferring change points in the spread of COVID-19 reveals the effectiveness of interventions
  Jonas Dehning et al. (Max Planck Institute, 15 May)
  SIR + Bayes estimation model
Related work

• Projecting the transmission dynamics of SARS-CoV-2 through the postpandemic period
Stephen M. Kissler, et al. (Harvard, 14 April)
SIR + Logarithmic regression model

• Mobility network models of COVID-19 explain inequities and inform reopening
Serina Chang, Emma Pierson, Pang Wei Koh, Jalone Gerardin, Beth Redbird, David Grusky & Jure Leskovec
SEIR + Network model

International infection research, carried out using a combination of data science models with accumulating big data and simulation models using AI and mathematical methods, has shown early results.
Conclusion

• We developed a new SEIR model that takes into account the influx risk, proposed a method that enables accurate prediction of infected people in the region, and analyzed the estimation results for Sapporo City and Tokyo.

• The impact of the risk of influx to Sapporo was analysed, and it was shown that the spread of infection in November could have been reduced by less than half if the number of influxes had been limited after the summer.

• We examined the infection prevention measures called for in the declaration of a state of emergency in the Tokyo metropolitan area, and based on the number of effective reproduction for each prevention measure in the individual-based model, we made a prediction using the SEIR model.
The significance of simulation

• Accuracy is sought, but the future is always uncertain

• Simulation is used to help make decisions rather than to seek the correct answer

• It should leave room for a wide range of interpretations and allow people to show off their skills.