Research Article

Effect of Human Movement on the Spread of COVID-19 in Thailand

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ABSTRACT

In December 2019, the first case of coronavirus (COVID-19) was reported in Wuhan, China. The first case reported in Thailand was in Bangkok during January 2020. The first large outbreak occurred at Bangkok's Lumpini Stadium in March. Those who were infected had visited the stadium for a boxing tournament. Many people left Bangkok and moved to other provinces to escape possible infection as the number of cases in Bangkok began to increase. This led to further infections in the other provinces. In this study, we estimated the number of exported cases from Bangkok to other provinces in Thailand during April 2020 using the probability of infection and travel volume from the Ministry of Tourism and Sports in April 2019. Our results found that the total estimated cases were 1,882 (95% credible interval 1,781-1,980), which was more than twice the number of actual reported cases. In this study, we found that when the travelling rate was reduced to 60%, the total estimated cases corresponded to the reported cases (740, 95% credible interval 684-795). We also found that the estimated cases depended on the rate of travel, thus decreasing the travelling rate led to a fall in the number of cases. The findings show how the reduction in traveller numbers can reduce the number of cases, which supports the government's lockdown policy. The model may also be applied to a possible second COVID-19 wave in Thailand.

Keywords: COVID-19; Human Movement; Thailand

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Introduction

The first case of coronavirus disease 2019 (COVID-19) was reported in Wuhan, China in December 2019 [1]. The main symptoms of COVID-19 are fever, dry cough, and tiredness. Other symptoms can happen in some patients such as aches and pains, nasal congestion, headache, conjunctivitis, sore throat, diarrhoea, and loss of taste or smell or a rash on the skin or discoloration of the fingers or toes. Sometimes, some people who become infected are asymptomatic or exhibit very mild symptoms [2].

As of 5 February 2020, there have been more than 24,550 cases of COVID-19 infection confirmed in China. More than 190 cases have been outside China. In Thailand, the first reported cases of COVID-19 infection were in January 2020 in people who visited the stadium for a boxing tournament that was held there. Many of the people who attended the tournament came from the country areas. When they went home, it led to the spread of infection into other provinces. Thus, the outbreak started to expand by the end of March. Then, the government started to close entertainment centres in March due to the infections that occurred at Bangkok's Lumpini Stadium.

In April 2020, the reported cases were found in 68 of the 77 provinces of Thailand. However, the most confirmed cases occurred in Bangkok. The main reason for spreading COVID-19 to the country is people travelling from Bangkok to other provinces due to lockdown. In April, there was the Songkran festival, which was a long holiday. This festival could lead to increasing the number of cases by people travelling in Thailand. The government has been trying to control the COVID-19 outbreak in Thailand through the lockdown policy. Songkran festivities were stopped as people were asked to remain at home under the lockdown policy in early April. The businesses began to lay off extra staff and some businesses were closed. Many smaller businesses closed permanently, resulting in increased unemployment. Foreign visitors were prevented from returning to their home countries, as travel was restricted. Many of these people left Bangkok and moved to the provinces to escape possible infection as the number of cases in Bangkok began to increase. This led to further infections in the provinces as some of these people were infected.

During the lockdown policy, people had stayed at home and worked from home since April 2020. However, people still moved around in the country but less than usual. Thus, travel in Thailand was not actually stopped when the government took the lockdown measures. The travelling rate can help to suggests how many people move elsewhere during the lockdown policy. Therefore, we want to examine the impact of the government's lockdown policy by using the travelling rate.

In these concerns, we can estimate the risk of exported cases from Bangkok by using a model-based approach. These results are compared with the number of reported cases and related to the rate of travel to estimate the number of cases exported from Bangkok. The model indicated that the estimated number of cases matches the number of reported cases.

Methods

Firstly, we imported the reported cases and travelling data for use in our model. The reported cases of Coronavirus 2019 (COVID-19) were retrieved from the Ministry of Public Health of Thailand [3]. Reports concerning each province are generally published daily. In this work, we interest in the reported cases of Bangkok as it is the most populous city and area of Thailand. There are two major airports in Bangkok catering for travel, and the first reported cases of COVID-19 occurred in Bangkok.

The statistics were obtained from the Domestic Tourism Statistics for each province from the Ministry of Tourism and Sport of Thailand. To estimate the inbound travellers of each province for April 2020, we used the number of travellers in April 2019. The number of travellers of each province is shown in Figure 1.

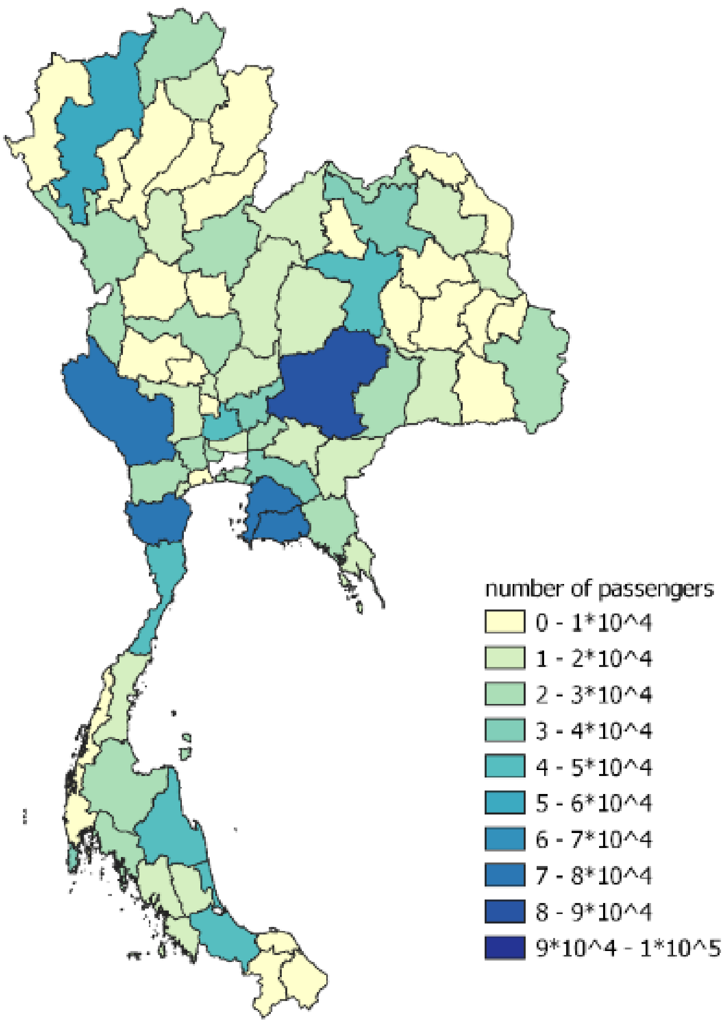

Figure 1 The number of people who travel from Bangkok to each province. Data were extracted from the Ministry of Tourism and Sports in April 2019.

Afterwards, we modified a previously described model [4] to evaluate the risk of travel-associated COVID-19 case exportation from Bangkok, Thailand. We used the inbound passenger volumes of each province, that travel from Bangkok, to quantify the number of cases (both symptomatic and asymptomatic) that will be the exported COVID-19 cases over the April outbreak period. This model had three parts that are the travelling rate, the probability of COVID-19 infection, and the exported COVID-19 cases.

We firstly estimated the number of travellers from Bangkok to other provinces by assumed that only 10% of all tourists in April 2019 (Figure 1) as the number of passengers from Bangkok in April 2020. This assumption was calculated by comparison with some provinces that had reported data. The foreign tourists could not go to Thailand, so we considered only Thai tourists as inbound travellers. In this work, we studied the travelling rate to find the effect of human movement on the first outbreak in Thailand. The percentage of travellers in each province was varied from 10 to 100, which is defined as the travelling rate. The number of travellers was assumed to be the same rate for all provinces. The travelling rate was assigned to observe the relation between traveling and exported COVID-19 cases from Bangkok. To concern about the stochastic event, the number of passengers was drawn from normal distribution in each simulation. We also adjusted travelling rate for comparison between the estimated cases from our model to the reported cases in April. We then find the travelling rate that can make the exported cases fit the reported cases.

Next, we estimated the number of infected cases in each province that would be expected to enter each province, using the probability of infection (P) by drawing from a binomial distribution with the mean of the number of passengers. The probability of infection for a given month was calculated as follows [5]:

$$P = 1 - \exp(-f\beta I/N),$$

where β is the transmission probability, I is the total number of infections in Bangkok adjusted with the probability of symptomatic cases, and f is the scaling factor. The probability of infection is the probability of the traveller from Bangkok can be the infected people. We used the number of reported cases in March for parameter I and the Bangkok population in 2019 for the parameter N. The reported data must be adjusted with the probability of symptomatic cases to estimate all infected cases in March 2020. The probability of infection was used for calculating the infected number, who can export from Bangkok in April 2020. The parameters that were used for calculating the probability of infection and the number of infections in April 2020 are shown in Table 1.

Table 1 General parameters

Parameter	Value	Detail	References
Annualized incidence in Bangkok in April 2020	794	Reported cases are assumed to represent the incidence of symptomatic COVID-19 infection and are the total number of infections (I) for estimating probability of infection	[3]
Population in Bangkok	5,676,648	Population in Bangkok was reported in 2019 represent the population (N) for estimate probability of infection	[6]
Probability case is symptomatic	0.48	Using for calculating the scaling factor	[7]
Transmission Rate	0.45	Using for estimating probability of infection	[8]
Number of passengers in each province for April.	400-42000	Assumed normal distribution; mean is monthly inbound passengers from each province; assumed the SD is 10% of the monthly passenger volume and using for calculating the number of infections.	[9]
Travelling rate	10-100%	To study the impact on the exported cases.	Assumption

Then, we can estimate the exported COVID-19 cases by considering the infected individuals using parameters in Table 1 and Table 2. Table 2 shows the parameters used to estimate the information of infected cases in April 2020. The information that we need to estimate is the latent period, the infectious period, and time to infection. By drawing the distribution as described in Table 2, these parameters can be calculated. The individuals, who stay in Bangkok, will be the exported COVID-19 case, if the summed total time of the latent period (drawn from gamma distribution), the infectious period (drawn from gamma distribution), and the time to infection (drawn from uniform distribution) is greater than the exposure duration as shown in Figure 2. In this model, the time to infection is the estimated time of the individuals, that visited the outbreak area in Bangkok. If the individuals visited the outbreak area and got infected, the time to infection is zero. Each infected individual was determined to have latent and infectious periods with the time to infection. The exposure duration represents the time of people, who were spending in Bangkok and can be infected. We estimated the exposure duration by looking at how long it has taken for residents to return home after the COVID-19 outbreak began. Thus, we estimated the exposure duration as a 30-day. If the infected individuals had the summed total time less than the exposure duration. It means that infected individuals were not the exported COVID-19 case. We reported the mean and 95% credible interval (CrI) of the number of exported cases from Bangkok from 1,000 simulation runs [10].

Table 2 Parameters to estimate the exported COVID-19 cases

Parameter	Value	Detail	References
Latent period (days)	μ=4.0, k=4	Latent period assumed as gamma distribution and used for finding the latent period of each person.	[11]
Infectious period (days)	μ=5.0, k=4	Infectious period assumed as gamma distribution and used for finding the latent period of each person.	[11]
Exposure duration (days)	30 days	We assumed that Thai people had stayed in Bangkok for 1 month (30 days) while the disease was spreading.	Assumption
Time to infection (days)	min=0, max=30	Assumed as uniform distribution and used for estimate time to infection of each people.	[4]

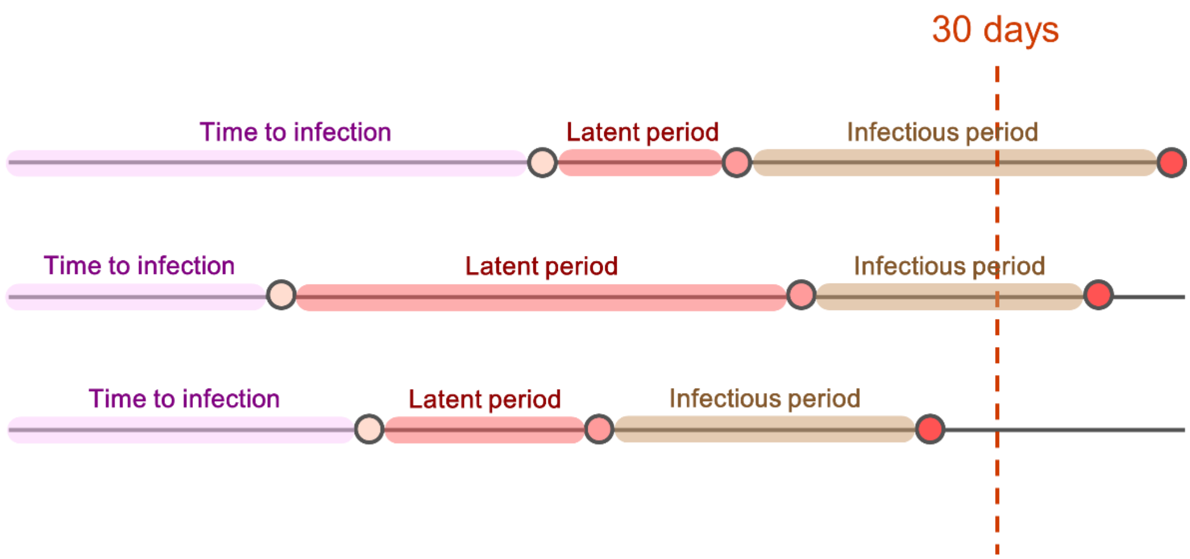

Figure 2 Example of the model process with 3 scenarios. The first and second person was the exported COVID-19 cases, but the third person was not.

Results and Discussion

The COVID-19 outbreak in Thailand has started since January 2020 and is ongoing. At the end of April, the total number of cases were more than 2,950 cases. We can estimate the COVID-19 cases of each province in April 2020 by using an average of estimated cases from this model.

The estimated cases from the model depended on travel volumes and number of cases in Bangkok. Therefore, the ranking of estimated cases was same as the ranking for inbound passengers in provinces such as Nakhon Ratchasima was the first rank of inbound passengers and the first rank of estimated cases too. The total estimated cases in every province of Thailand (excluding Bangkok) were 1,882 cases when the travelling rate was one hundred percent (Figure 3a).

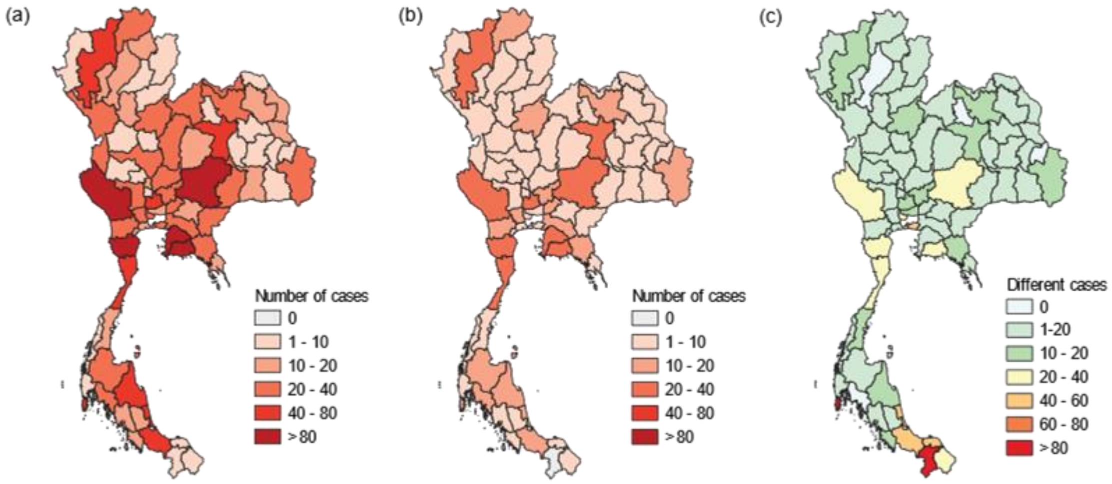

Figure 3 The number of estimated cases (reported by the mean in each province and excluding Bangkok) that had a travelling rate of 100% (a). The number of estimated cases that can be calculated by using this model in 60.62% reduction rate (b). The different cases in each province that compared estimated cases in (b) with real data (c).

The estimated cases normally aligned with the travelling rate, when the provinces received more travellers, the estimated cases also increased. We plotted the total estimated cases with each travelling rate to find the travelling rate that made the estimated cases fitted to the reported cases. Our results indicated that the total estimated cases (740, 95% CrI: 684-795) fitted the reported cases when the travelling rate was reduced by 60.62% (Figure 3b). From this finding, we summarize that the number of travellers in Thailand was reduced by 60.62% in April 2020 due to the lockdown policy. Our results could imply that the government policy can reduce the infected cases during April 2020.

Figure 3c shows the different infected cases between the estimated cases by using 39.38% of the travelling rate (reduction rate 60.62%) with the reported data. The reduction rate can be defined as a decrease in the rate of travel. We found that The most error cases were in Phuket (the average was 16 [95% CrI: 9-25] cases) and Yala (the average was 0 [95% CrI: 0-2] cases) while the least error cases were in Amnat Charoen (the average was 1 [95% CrI: 0-4] cases), Krabi (the average was 12 [95% CrI: 5-19] cases) Lampang (the average was 4 [95% CrI: 1-9] cases) and Nong Bua Lamphu (the average was 1 [95% CrI: 0-4] cases).

The estimated cases with a reduction rate of 60.62% in each province were hardly different from the reported cases in April 2020. Figure 3c shows the different cases almost in grey and green scale, which means that the estimated cases were close to the reported cases. However, in some provinces on Southern Thailand such as Yala, the reported cases are extremely higher than the estimated cases. We also plotted the results of the reduction rate as shown in Figure 4. We found that the exported cases during the infectious period were higher than the exported cases during the latent period. The results indicated that the exported people could spread the diseases during travel or on the first day of arriving. Reduced the travelling rate could rapidly reduce the infected cases.

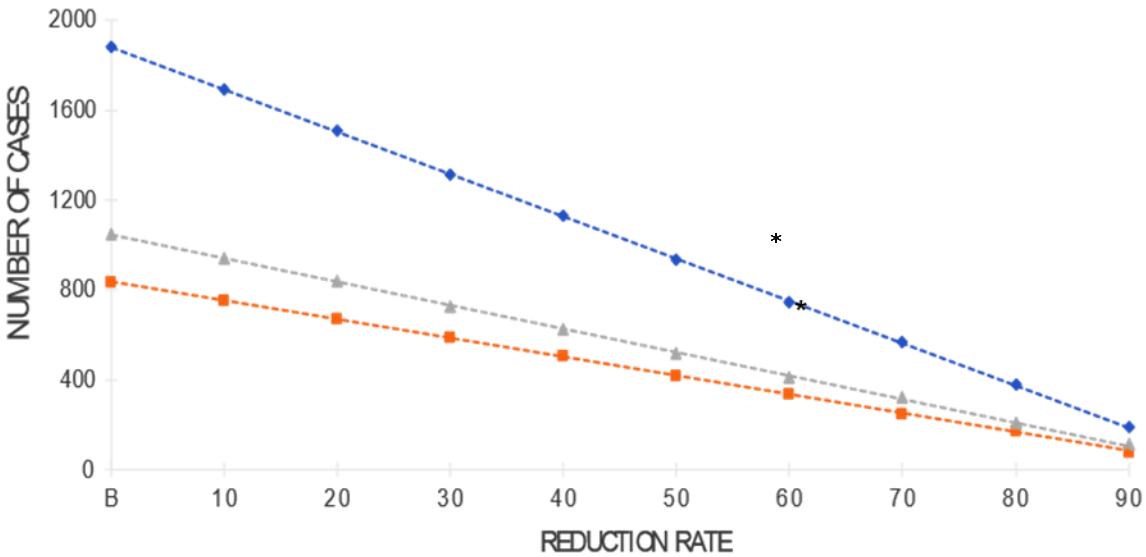

Figure 4 The total exported cases excluding Bangkok (blue line), where the * is the 60.62% reduction rate. The total cases during the infectious period are defined as the people who are infectious and could transmit the disease to other people (grey line). The total cases during the latent period are defined as the people who are infected but not infectious yet (orange line).

The rate of travel resulted in a reduction of estimated cases. When the travelling rate was reduced, the estimated cases also decreased, as shown in Figure 4. However, we were not interested if the travel rate was 0 percent because the outbreak cannot occur if people are not moving. The estimated cases when the travel rate is 100% are extremely more than the number of cases when the travel rate is 10%. In April 2020, the reported cases remained elevated. Therefore, the lockdown policy can control the outbreak when the travel rate is less than 39.38%. The exported cases that we obtained depended only on travel volume from Bangkok, (probability of infection is constant in this case) but in real life, people could go from another origin such as a lot of reported cases in southern Thailand were local people who visited Malaysia [12]. Therefore, Bangkok was not the only origin of COVID-19 in Thailand. There were other sources of COVID-19. Malaysia and other neighbouring countries could have influenced the number of reported cases in Thailand. Travel volume, estimated from travelling in each province in 2019, indicated that travel volume was higher than the travel volume for the same period in 2020, because the Songkran Festival for 2020 was cancelled and a lot of people stayed at home. In addition, the lockdown of 2020 suggested that people could not travel. However, some people went to their hometowns because the COVID-19 outbreak in Bangkok was so bad in March 2020.

This model did not concern foreign travellers because foreign people could not come to Thailand after the lockdown which, began on 26th March 2020. The model focuses only on the main source of the outbreak, which may spread to other places. This study did not consider environmental factors such as eating in restaurants, stage quarantine and wearing of surgical masks. The environmental factor can affect the reported cases such as wearing surgical mask could decrease the rate of infection because COVID-19 was infectious from person to person through small droplets from the nose or mouth, which were expelled when a person with COVID-19 coughed, sneezed, or spoke [13].

This output model could apply to the second COVID-19 outbreak in Thailand that has started in December 2020. The imported cases that were the spreader in the second outbreak came from Myanmar. These reported cases are migrant workers in Samut Sakhon [14]. It means the second outbreak source of Thailand is not Bangkok that is the first outbreak source but is Samut Sakhon. The world situation of COVID-19, the numerous reported cases were not in China but in the United States and some countries in the Americas because there were more than 11,420,000 cases in the Americas and more than 5,260,000 cases in the United States which ranks first in the world in the number of cases [15]. This model could be used for monitoring the spread of disease worldwide, however factors such as the movements of migrant workers from Myanmar that have been the infector in the second wave of COVID-19. The exported source change to Samut Sakhon. The other advantage of this model is that it allows us to estimate the number of infected, who are in latent and infectious periods. This may be useful for preparing resources to treat infected cases, such as the demand for state quarantine and healthcare services in each province.

Conclusion

The results indicate that, in the cases where there are no control measures, the estimated number of exported cases is more than twice the number of actual reported cases. The total estimated cases fitted the reported cases when the travelling rate was reduced by 60.62%. We found that the number of estimated cases in some provinces were similar to the reported cases. The estimated cases depended on the rate of travel, thus decreasing the travelling rate from 100% to 10%, the number of estimated cases also decreased. The rate of travel was used to study the impact of the lockdown policy on the outbreak of COVID-19. This implies that reducing travel may help contain the outbreak of COVID-19 in April 2020. Our results indicated that the ban of the Songkran festival could decrease the number of cases. This finding highlighted the idea that the reduction in traveller numbers could reduce the number of cases, which supported the government lockdown policy. However, this control measure could not fully control the number of exported cases to other provinces.

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