

Route prediction model of infectious diseases for 2018 Winter Olympics in Korea

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Abstract. There are many types of respiratory infectious diseases caused by germs, virus, mycetes and parasites. Researchers recently have tried to develop mathematical models to predict the epidemic of infectious diseases. However, with the development of ground transportation system in modern society, the spread of infectious diseases became faster and more complicated in terms of the speed and the pathways. The route of infectious diseases during Vancouver Olympics was predicted based on the Susceptible-Infectious-Recovered (SIR) model. In this model only the air traffic as an essential factor for the intercity migration of infectious diseases was involved. Here, we propose a multi-city transmission model to predict the infection route during 2018 Winter Olympics in Korea based on the pre-existing SIR model. Various types of transportation system such as a train, a car, a bus, and an airplane for the interpersonal contact in both inter- and intra-city are considered. Simulation is performed with assumptions and scenarios based on realistic factors including demographic, transportation and diseases data in Korea. Finally, we analyze an economic profit and loss caused by the variation of the number of tourists during the Olympics.

1. Introduction

In order to predict for the infection route most countries of world use mathematical models of infectious diseases. Longini et al. [1] and Carrat et al. [2] have explained the transmission of infectious diseases such as measles and SARS by a mathematical modelling. Glenn et al. [3] predicted the transmission of infectious disease using the SIR model based on pandemic influenza A data. In [4], Susceptible-Infectious-Recovered (SIR) Model was applied for the prediction of the transmission of infectious diseases in Vancouver Olympics considering an airplane as a transportation factor. However, with the development of the modern transportation system, the spreading speed and route of infectious diseases became faster and more complicated. Therefore, transportation factor including only an airplane in [4] is very limited.

In this study, we propose a multi-city transmission model to predict the infection route during 2018 Winter Olympics in Korea based on the pre-existing SIR Model [5]. Various types of transportation system such as a train, a car, a bus, and an airplane for the interpersonal contact in both inter- and intra-city are considered. Simulation is performed with assumptions and scenarios based on realistic factors including demographic data from Statistics Korea [6], daily traffic data available from the Korean Statistical Information Service (KOSIS) [7] and diseases data from the Korea Centers for Disease Control and Prevention (KCDC) [8]. Although this work does not include all the possible

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factors related to infectious diseases, it can be a guideline to predict the infection route and minimize an epidemic disaster through this basic modeling.

2. Multi-city transmission model

We represented the transmission of pandemic influenza A in Korea based on pre-existing SIR Model [5]. Here individuals are classified as susceptible ($S(t)$), infectious ($I(t)$), and recovered ($R(t)$) and we assume that the population and the traffic flow are homogeneous. Our multi-city transmission model includes modes of transportation in order to consider the interpersonal contact over a broad range. Therefore, our model sufficiently predicts the transmission of infectious diseases because of including interpersonal contact in a broad range and based on analysing the traffic data. Our model is the system with nonlinear differential equations:

$$\begin{aligned}\frac{dS_i[t]}{dt} &= -\alpha \left[\frac{I_i[t]}{N_i[t]} + \sum_{j \neq i} \left(\frac{m_{ij}}{N_i[t]} + \frac{m_{ji}}{N_j[t]} \right) \frac{I_j[t]}{N_j[t]} \right] S_i[t] \\ \frac{dI_i[t]}{dt} &= -qI_i[t]\theta[t - t_{ii}] - \beta I_i[t] + \alpha \left[\frac{I_i[t]}{N_i[t]} + \sum_{j \neq i} \left(\frac{m_{ij}}{N_i[t]} + \frac{m_{ji}}{N_j[t]} \right) \frac{I_j[t]}{N_j[t]} \right] S_i[t] \\ \frac{dR_i[t]}{dt} &= qI_i[t]\theta[t - t_{ii}] + \beta I_i[t]\end{aligned}\quad (1)$$

where α represents the rate of infection (number of adequate contacts per unit time [contacts/day]), β is the rate at which infected people recover (1/day). m_{ij} is the number of persons moving from city i to city j . m includes transportation factors by train, passenger car, bus, and airplane. $(m_{ij}/N_i[t]) \times (I_j/N_j[t])$ is the probability that a person that migrated from city i to city j can contact with an infected person in city j . Therefore $(m_{ij}/N_i[t]) \times (I_j/N_j[t]) \times S_i[t]$ describes the number of susceptible persons in the city i , that contact with infected persons in city j through the transportation. $qI_i[t]$ is the number of persons in city i that inoculated according to the rate of antiviral drug (q) to infected persons at time t . $\beta I_i[t]$ is the number of infected persons in city i that recovered with recovery rate β . $\theta[t - t_{ii}]$ is the Heaviside unit step function as

$$\theta[t - t_{ii}] = \begin{cases} 1 & \text{for } t > t_{ii} \\ 0 & \text{for } t < t_{ii} \end{cases} \quad (2)$$

The timing of the antiviral drug is t_{ii} , which can be set differently for each city.

3. Results

The simulation calculated the spreading course of infectious diseases during the outbreak of pandemic influenza A prior to the 2018 Winter Olympics in Korea using Mathematica 6.0. The simulation covers January 6, 2018 to April 24, 2018 ($t=1 \sim 100$ day) and the Winter Olympics is held from February 9, 2018 to February 25, 2018 ($t=25 \sim 42$ day). The following suppositions have been set up in order to predict the spreading course of infectious diseases. Pandemic influenza A occurs from February 5 to February 14 ($t=21 \sim 30$ day) at the Incheon International Airport and 25 people (0.05%) out of Incheon International Airport population are carriers. And the foreign tourists enter the country through Incheon International Airport during this period. The simulation has selected five major cities with a large flow in population using the population data of [6]. They are Seoul (10,223,243 people), Incheon International Airport (51,224 people), Gangneung (219,245 people), Pyeongchang (43,706 people) and Wonju (320,563 people). It was assumed that Pandemic influenza A spreads using only the transportations methods of trains, passenger cars, buses and airplanes. Seoul has the largest transportation system and Incheon International Airport, Gangneung, Wonju and Pyeongchang are

followed in order [7]. However, Pyeongchang, the hosting city of Winter Olympics, was assumed that it is the second after Seoul in terms of the traffic flow during the Winter Olympics.

Table 1. Pandemic influenza A occurs during $t=21\sim30$ day at the Incheon International Airport, proportion of infectious persons by each city during the Olympics according to the three types of scenario. ($I=0.05\%$, $q=0.03$ (3%)).

	Incheon Airport	Seoul	Wonju	Pyeongchang	Gangneung
Scenario 1	23 %	25 %	16 %	26 %	16 %
Scenario 2	16 %	17 %	10 %	17 %	10 %
Scenario 3	22 %	23 %	15 %	23 %	15 %

There are three types of scenario. First, the antivirus drug is not administered to all cities during the Winter Olympics. Second, the antivirus drug is administered to Pyeongchang which is the hosting area of Olympics on February 9th ($t=25$ day) which is the first day of Winter Olympics. Third, the antivirus drug is administered to Pyeongchang on February 19th ($t=35$ day) which is a day in the middle of Winter Olympics to compare how the proportion of in Winter Olympics according to the three types of scenario. Here, q was assumed as 3%, α was assumed as 17.535% and β was assumed as 6.25%. As a result, the fact that proportion of infectious persons getting decreased could be found if the antivirus drug is quickly administered in all cities. In other words, the proportion of infectious persons has reduced considerably in scenario 2 than scenario 3. And the proportion of infectious persons in scenario 2 has reduced considerably in Pyeongchang which is the antivirus drug administered area. Next were in the order of Seoul with a lot of traffic, Incheon International airport and Gangneung or Wonju with little traffic.

Figure 1 has compared the following with same conditions as Table 1. (a) proportion of infectious persons in all cities during the Winter Olympics, (b) antivirus treatment cost of infectious persons (the price of Tamiflu is \$22 per person per dosage), (c) rate of visiting foreign tourists and (d) cost of economic loss due to decrease of foreign tourists. Here, the total number of foreign tourists are 195,000 and \$421 million is spent [9]. As a result of simulation, (a-c) reduces the number of infectious persons and treatment cost as the administration of antivirus drug gets earlier while the fact that visiting foreign tourist also getting increased has been verified. And (d) has verified the fact that economic loss is great as the consumption of foreign tourist gets reduced as the treatment of infectious persons gets delayed.

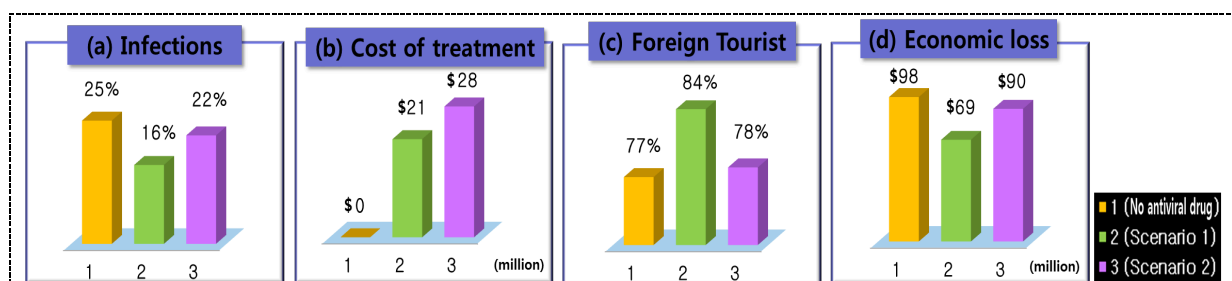


Figure 1. Pandemic influenza A occurs during $t=21\sim30$ day at the Incheon International Airport, (a) proportion of infectious persons, (b) antivirus treatment cost of infectious persons, (c) rate of visiting foreign tourists and (d) cost of economic loss due to decrease of foreign tourists.

4. Discussion

This paper has proposed a Multi-city transmission model for tracking and predicting the spreading course of pandemic influenza A by extending the SIR model while simulating the epidemics of

contagious disease during the outbreak of pandemic influenza A during the period of the Winter Olympics of Korea in 2018. As a result of the calculation, the infectious disease spreads out being influenced by the transportations and the time and position for the administration of the antivirus with high priority can be determined by the analysis based on the amount of the traffic. Also, the alternative for attracting most number of tourists could be found through an economic analysis followed by increase or decrease of tourists.

The simulation is limited in that the modes of transport only included buses, trains, passenger cars, and airplanes and only 5 cities are considered. Therefore, the future study will be researched by adding more cities and various types of transportation.

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