The Role of Different Transportation in the Spreading of New Pandemic Influenza in Mainland China

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Abstract—**In March 2009, influenza A(H1N1) was first detected in Mexico, and quickly spread to other countries. Civil aviation traffic played a very important role during the global spread of the epidemic. We build a spatial-temporal model to simulate the spreading process of influenza A(H1N1) at two spatial scales: simulating case evolution within province and inter-provincial spread in mainland China. Using inter-provincial passenger traffic data of railway, civil aviation and highway transportation, we calculate the daily probability of mobility of individuals between the 31 provinces by different transportation routes and analyze the effect of these three forms of transport upon travel between provinces. Simulation experiments about spreading process of pandemic influenza A(H1N1) have been done with different probability data. According to these simulation data, we evaluate the influence on the spatial distribution of cases at the national scale caused by different modes of transportation.**

Keywords-pandemic influenza A(H1N1); simulation model; traffic ; spatial distribution

I. INTRODUCTION

In 2009，the pandemic of influenza A(H1N1) resulted in huge numbers of human fatalities and resulted in massive economic costs around the world. Aeroplanes played an important role in the spatial spread of disease. Previous work shows that, up to 25 May 2009, three quarters of countries with significant air traffic from Mexico had reported imported cases from Mexico [1].

Historical experience shows that the transmitting processes of epidemic influenza are always affected by traffic. For example, in 1918, the Spanish influenza epidemic broke out in an army in the USA, and spread to Europe and then all over the world. In 1957, influenza broke out in Guizhou province in China, and then spread to other countries via airline travel.

So, it is important to study the effects of traffic when influenza breaks out which will enable real-time actions to contain influenza to be carried out.

II. SIMULATION MODEL

In paper [2, 3], a simulation model is developed to depict the transmission of pandemic influenza A(H1N1). The model consists of two spreading processes on two scales: the first one is used to describe the development of influenza A(H1N1) in each province, the second one is designed to express cases flowing between the 31 provinces (Fig. 1).

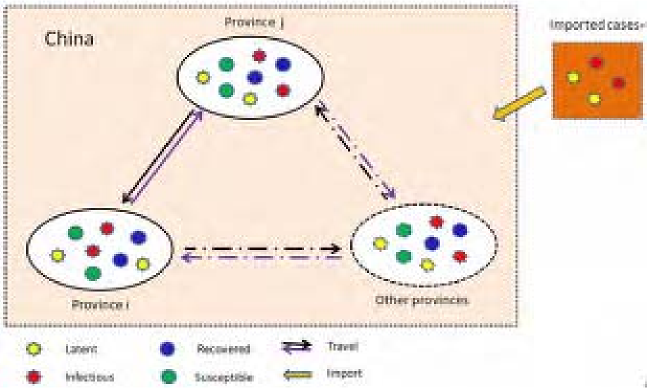

Figure 1. Structure of the simulation model

A. Development of Influenza in Each Province

The SEIR compartmental model is introduced to depict the development of influenza A(H1N1) within each province. In SEIR compartmental model, each individual is classified by one of the discrete states such as susceptible(S), exposed(E), infectious(I) and recovered(R) [4-6]. The infectious are further subdivided into asymptomatic infectious and symptomatic infectious with P_a and 1- P_a rates respectively. If a susceptible individual contacts an asymptomatic or symptomatic infectious individual, he/she may be infected and hence move into latent state at a rate of $\gamma\beta$ or β, and then move into the infectious state at a rate of ε. The infectious individual will recover at a rate of μ (Fig. 2).

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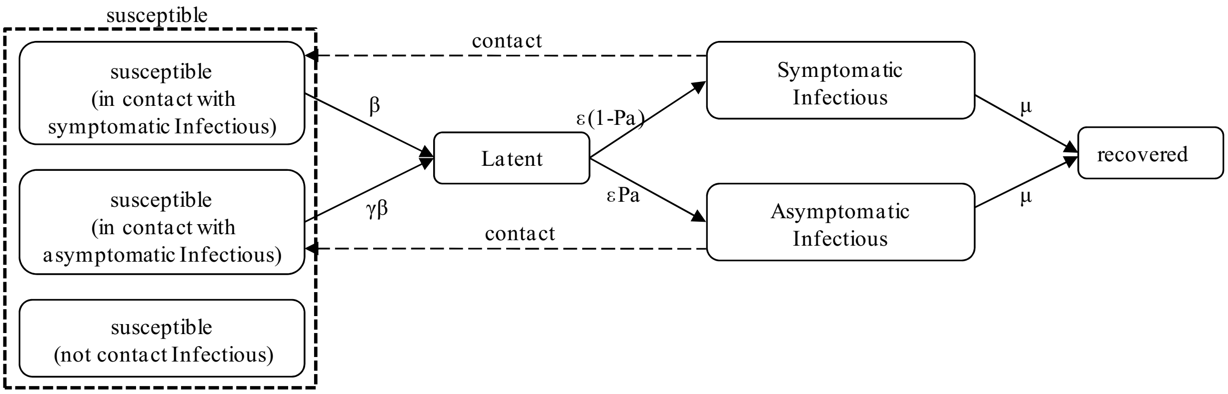


Figure 2. Epidemic model in each province

B. Flowing of Influenza A(H1N1) among Provinces

Traffic has played an important role in the transmission of influenza A(H1N1) between the 31 provinces. In this paper, the probability of people travelling among provinces in 2008, is used to describe the flowing processing of influenza cases between provinces. The probability is calculated as in (1)

$$P_{ij}^{*} = \frac{N_{ij}}{365 \cdot Sum_{i}} \qquad (1)$$

Where P_{ij}^{*} is the daily probability of one person travelling from province i to j， N_{ij} is the number of passenger from province i to j in 2008， Sum_{ij} is the total population of province i.

C. Imporedt Cases

Imported cases are divided into three states, latent, asymptomatic infectious and symptomatic infectious.

III. CALCULATING TRAVEL PROBABILITY OF DIFFERENT TRAFFIC

In this study, railway, civil aviation and highways are taken into account to evaluate their roles in the spreading of influenza A (H1N1) between provinces. People's travelling probability used in our simulation model is calculated from traffic data of different forms of transport.

We simulate the actual situation of people's mobility among 31 provinces when influenza spreading in 2009 based on the interprovincial traffic data in 2008.

A. Civil Aviation

Airport to airport passenger data is used to inform the civil aviation model [7, 8]. Interprovincial airline transport is therefore calculated from these data by (1).

B. Highway

2008 highway travel data is used [9], whilst interprovincial travel probability is calculated using the process shown in Fig. 3.

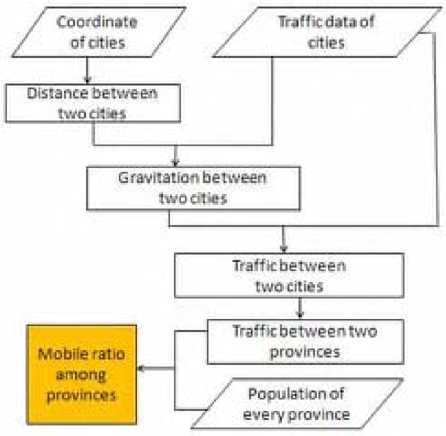


Figure 3. Process of calculating the mobile ratio via highway

1) Inter-municipal distance and gravity coefficient

Based on the coordinates of each city [10], we calculated the distance between each pair of cities. A gravity model [11, 12] was introduced to compute the gravity coefficient of each pair of cities according to distance and passenger numbers as follows,

$$V_{ij} = m\frac{N_i N_j}{D_{ij}^{\alpha}} \qquad (2)$$

where N_i ， N_j are the passenger numbers of city i and j in 2008， D_{ij} is the distance between city i and j, V_{ij} is their gravity coefficient, α is a parameter representing the weight of distance which is set to 3.5 here whilst m equals 1 [11, 12].

2) Ratio of passenger between tow cities

Based on the gravity coefficient, we can get the ratio of passenger number from municipal *i* to *j* compared with the number from municipal *i* to the other 265 municipals, i.e., P_{ij} using the following formula

$$p_{ij} = \frac{V_{ij}}{\sum\limits_{j=1,\ldots,265;\, j\neq i} V_{ij}} \tag{3}$$

3) Passenger between municipals (cities)

We now calculate the passenger numbers from municipal *i* to *j* using formula as in (4).

$$\mu_{ij} = N_i \cdot p_{ij} \tag{4}$$

μ_{ij} is the number of passengers from city *i* to city *j*.

4) Passengers between provinces

Having obtained passenger numbers between cities, we can use these to determine flow between provinces.

5) Mobile probability among provinces

At last, we can calculate the daily personal travelling probability from province *i* to *j* by (1).

C. Railway

In this part, we should acquire the inter-provincial railway traffic data in 2008, according to the available data including inter-provincial railway traffic data in 2004 [13] and other statistical data [14]. The traffic data of Tibet [15] has to be taken into account separately, because the railway was not completed until July 2006 and there were no data in 2004. We designed a process to deal with these problems (Fig. 4).

1) Growth of railway traffic

In each province, traffic growth in 2008 compared to in 2004 is calculated using the following formula,

$$\Delta N_i^{2004-2008} = N_i^{2008} \text{-} N_i^{2004} \tag{5}$$

where $\Delta N_i^{2004-2008}$ is the growth, N_i^{2008} and N_i^{2004} are the traffic in 2008 and in 2004.

2) Proportion of inter-provincial trafffic

The percentage of traffic between province *i* and *j* to total traffic between province *i* to all 31 provinces, $\tilde{p}_{ij}$ was computed using (6),

$$\tilde{p}_{ij} = \frac{N_{ij}^{2004}}{\sum\limits_{j=0\ldots30} N_{ij}^{2004}} \tag{6}$$

where N_{ij}^{2004} is passengers from province *i* to *j*.

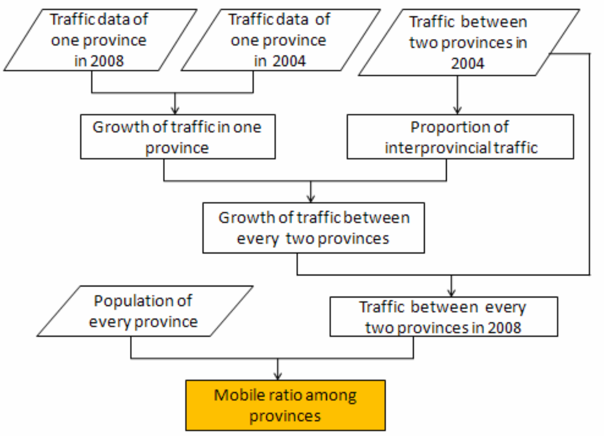


Figure 4. Process of calculating the mobile ratio via railway

3) Growth of railway traffic between each pair of provinces

We divide the total traffic growth in 2008 compared to in 2004 in each province into 31 parts between province *i* to *j* using (7), then we can get the traffic growth between each pair of provinces in 2008 compared to in 2004, such as between province *i* and *j*.

$$\delta_{ij}^{2008-2004} = \Delta N_i^{2004-2008} \cdot \tilde{p}_{ij} \tag{7}$$

4) Railway traffic between each coulpe of provinces in 2008

Then we can obtain the traffic between province *i* and *j* in 2008 by the following formula,

$$N_{ij}^{2008} = N_{ij}^{2004} + \delta_{ij}^{2008-2004} \tag{8}$$

5) Mobile probability among Provinces

We calculate the probability of daily personal travel from province *i* to *j* using (1).

In addition, railway data in Tibet in 2008 has to be calculated separately. The computing process is similar to computing highway data. We divided the traffic data of Tibet in 2008 into 30 parts based on the gravity coefficient of Tibet with the other 30 provinces.

D. Summary

The probability of personal travelling among 31 provinces (Fig. 5) shows that the probability of movement by highway and railway decays gradually as the distance increases, which is consistent with the study in [16]. Furthermore, the decay of highway is faster than that of railway. Civil aviation did not show this feature, instead, the traveling probability of two adjacent provinces is usually smaller.

Analysis about railway, highway and civil aviation shows that railway is the primary mode of transportation and highway is secondary when people travel among geographically adjacent provinces. However, when people travel among provinces geographically far apart, they inclined to select civil aviation. For some economically developed provinces, civil aviation and highway are the main forms of transport. So, it is unreasonable to consider only one transport when studying the spread of influenza A(H1N1) among provinces in mainland China. We should consider the interaction of railway, highway and civil aviation together.

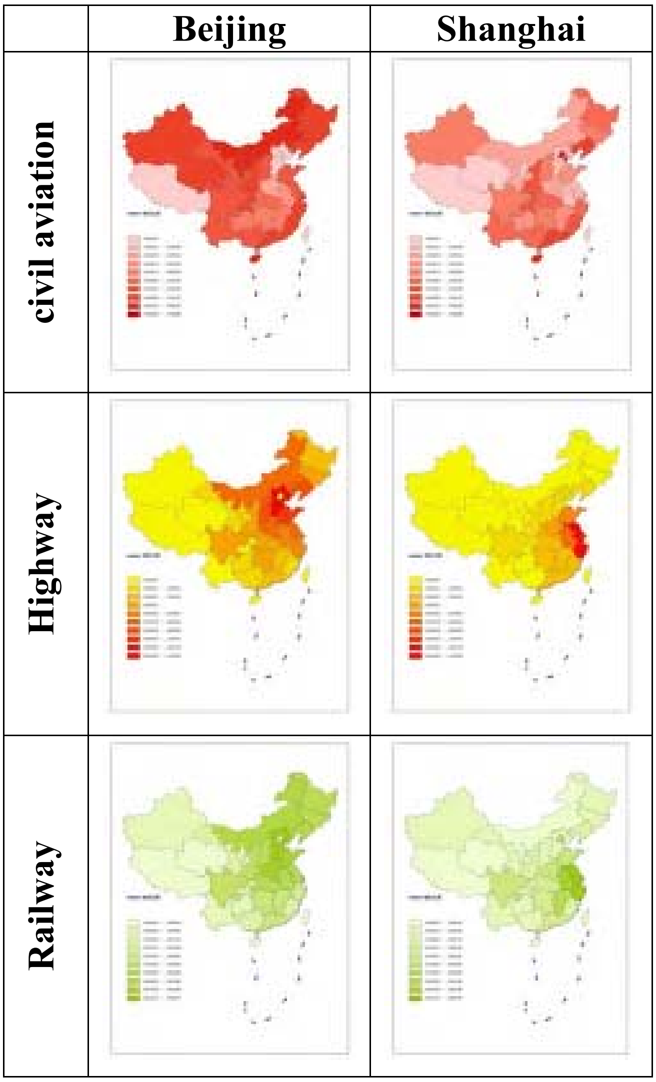


Figure 5. Travelling probability of three transportation

IV. SIMULATION EXPERIMENTS

We simulated the transmission process of influenza A(H1N1) in the early stages of spread in mainland China, from May 11 to June 13 (a period of 35 days), in 2009.

A. Parameter Setting

Based on the relevant research results about influenza A(H1N1) [17-24], we set the parameters in our model as follows, $1/\varepsilon=1.5$, $\gamma=0.5$, $1/\mu=2$, $P_a=0.33$, $R_0=1.75$, $\beta=1.05$.

B. Initial Case's Data

Data of the daily number of imported cases from Ministry of Health of China [25, 26] were used as initial data for simulation experiments. Imported cases from abroad were in two states, latent and symptomatic infectious, when they arrived in mainland China. So, we considered the number of latent and symptomatic cases (Fig. 6) and calculated the number of asymptomatic infectious by the number of symptomatic infectious and the parameter P_a=0.33.

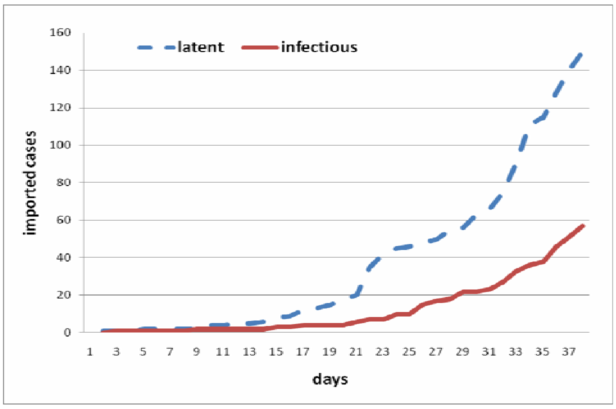


Figure 6. Imported cases

C. Traffic Setting

We set five scenarios for describing travel between the 31 provinces when simulating the spatial-temporal spreading of influenza A(H1N1). Four of them correspond to traffic scenarios including railway, highway, civil aviation and three transportations together, whilst the final scenario assumes no traffic.

D. Results and Discussion

Before May 24, in the five scenerios, the model predictions of the provinces with reported cases coincide well with observations. After May 29, differences began to appear. By June 13, the number of infected provinces for the five scenerios are 28, 18, 28, 31 and 17 respectively (Fig. 7).

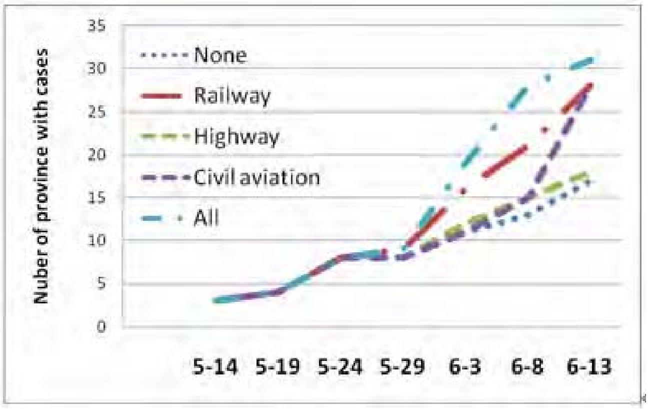


Figure 7. Number of province with cases

In the spreading process of influenza A(H1N1) in four experiments based on different traffic, the spatial distribution of provinces show a significant discrepancy between each other.

Railway plays a role in the spatial spread of infection earlier than highways and aero planes. On 29 May, the number of infected provinces under the scenerio of railway only began to be larger than that of highway and civil aviation. Up to 13 June, most of provinces had reported cases except Tibet, Xinjiang and Qinghai (Fig. 8). This is due to the fact that the railway is the primary transport mode for personal inter-provincial movement in mainland China.

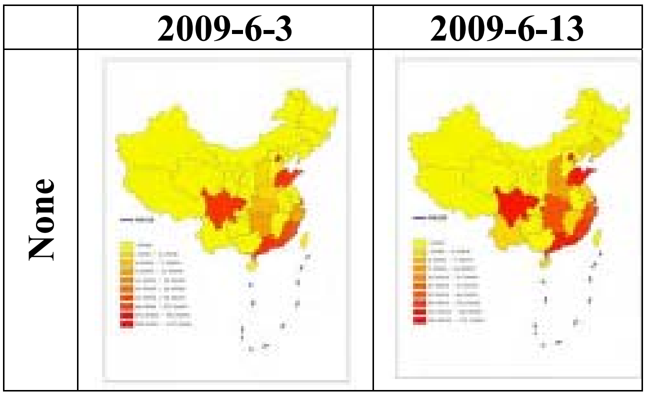
Highways began to have a more significant role from 3 June. Simulation results based on highways showed that provinces with cases were adjacent geographically. Up to 13 June, the number of provinces with cases was almost equal to the number of provinces which had imported cases (without any traffic). The role of highways was not obvious both in the spatial distribution and number of infected provinces in the simulation process.

The role of civil aviation in the spatial spread of disease was not obvious at the early stage. However, after 8 June, the effect of civil aviation was obvious both in spatial distribution and number of infected provinces.

In the model using all three modes of transport, the number of infected provinces increased faster than those using one form of transportation. On 13 June, all 31 provinces had reported cases. To some extent, it showed some overlay of the three modes of transport in spatial distribution.

Based on the above analysis, we suggest that in response to the interprovincial transmission of the epidemic in mainland China, in the early step，railways should be taken into account firstly to prevent and control its spread; highway and civil aviation should also not be neglected. When case numbers are high civil aviation will play an important role.

However, some problems still exist and may lead to a bias in the results, as geographic factors and intervention strategies during the travelling process are not taken into account. Future work will attempt to address these biases.



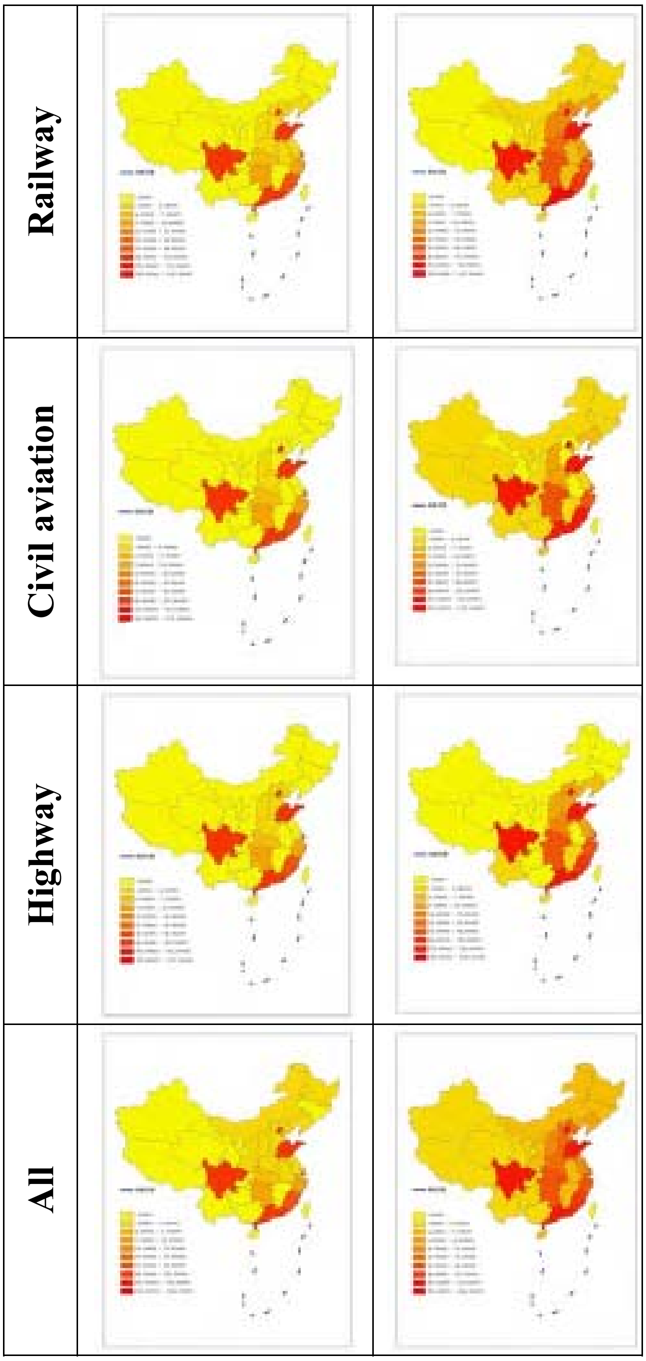


Figure 8. Spatial distribution of province with cases

I. CONCLUSION

A spatio-temporal simulation model of influenza A(H1N1) is constructed based on the SEIR model to simulate the spread of disease in mainland China. In this model, each province is a single unit, whilst railways, highways and civil aviation were used to model flow between provinces in accordance with a fixed ratio, calculated from traffic data.

By comparing the ratio of the three modes of transportation, we suggest that they should be taken into account together when studying the spread of influenza A(H1N1) among provinces in mainland China.

We carried out five different experiments with different transportation assumptions and showed that the spatial distribution of cases is affected by all three modes of transport. Railways and airlines should be considered during the early stages of the outbreak as a key transmission risk, they play a significant role in disease transmission between provinces. However, highways also should be taken into account, simultaneously.

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