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Super Spreader, Age Structure and Group Behavior: A Cluster of Influences on Influenza Diffusion within Public Transport Stations

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In pandemic, it's much difficult to tell which kind of intervention strategies is the most effective within a terminal. To achieve that, the influences that super spreader, age structure and group behavior impacted on the transmission had to be quantitatively evaluated. This paper was to propose a method capable of quantitatively analyzing the influences. First of all, the SEIR model got improved with influenza spread characteristics within terminal in individual level. Then behaviors of passengers in different groups optimized the social force model. Besides, both of them were fused in simulations within a terminal. Experiments indicated that super spreader impacted a lot on influenza transmission in departure; group behavior imposed a great influence on the spread in arrival and age structure generated a little impact. In departure and arrival, intervention strategies should get adjusted to arrest influenza development.

Key words: Influenza spread, Super spreader, Age Structure, Grout behavior, Individual contacts based SEIR model, Social force model.

Individual contacts based model is a small scale model, which regards individuals as cells or agents composed of a set of finite state and behavior rule. The framework of such models[1-3] considered the effect of interaction between etiology, host and environment on epidemic transmission in individual level. Hence, individuals' local interaction in rule space could get described effectively. However, this method has deficiency in expressing individual heterogeneity, complex social relation network among individuals and the autonomous behaviors.

Scholars put forward a series of pedestrian flow models for the researches of crowd behavior and characteristic, such as cellular automata model, magnetic force model, queuing model and social force model and so on. Among them, social force model[4-6] has received more and more attention. The pedestrian self-organization phenomenon and evacuation in panic are simulated. And large scale population movement is analyzed based on individual characteristics. Moreover, actual phenomenon such as 'arch effect' and 'fast that is slow' are simulated.

On foundations above, an individual contact based SEIR model fused with optimized social force model is proposed to quantitatively analyze the influences of the super spreader age structure and group behavior on influenza transmission. Attempt to propose effective intervention measures on the epidemic diffusion.

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MATERIALS AND METHODS

Influential factors needs to be considered

Probability distribution function of influenza diffusion

Influenza is contagious, spreads fast, and disseminates mainly through droplets in the air and contacts among individuals. The valid spread distance of droplets is usually less than 2 meters[7]. And the spread possibility correlates valid contact time[8], contact time within valid spread distance.

The spreading probability density function-$f(t)$ changes along with valid contact time *t*, has to follow Eq. (1) and Eq. (2). Sequentially, Eq. (3) is derived. Then probability distribution function $F(t)$ is given in Eq. (4).

$$f(t) = \beta(1 - \int_0^t f(\tau)d\tau) \quad (0 \le \beta \le 1) \qquad ...(1)$$

$$\int_0^{+\infty} f(t)dt = 1 \qquad ...(2)$$

$$f(t) = \beta \exp(-\beta t) \quad (0 \le \beta \le 1) \qquad ...(3)$$

$$F(t) = 1 - \exp(-\beta t) \quad (0 \le \beta \le 1) \qquad ...(4)$$

Super spreader

In terminal, passengers flow on specific directions and are more incline to the contacts induced from their own departure or arrival path. And there are much more procedures or services needed to be carried out in terminal. Conducting these procedures lessens the passenger interval and raises the likelihoods of getting contaminated. Furthermore, staffs in the terminals frequently contact with passengers. Once a staff in a terminal gets sick, it is highly possible for him becoming a super spreader which is the so-called super spreader phenomenon. Flu virus would get an extensive spread due to super spreader. Consequently, the control of contact behaviors with super spreader plays a key role in flu diffusion intervention within terminal.

Age structure

Since the spreading and infection of influenza is age structured and each age group has their own resistance to the grippe, age structure should get taken into consideration while studying the flu transmission characteristics within the public transport stations. Basing on the research in paper[9], Table 1 gives the infection rate β_i ($0 \le \beta_i \le 1$) of susceptible of ages when contacting with pathogens. Where, the highest infection rate lies in the 20-39 age groups, 14.30% while the lowest infection rate is 9.26% (above 60 years).

Group behavior

Passengers can be classified into three categories basing the number of passengers[10], namely, tour group passengers, accompany passengers and individual passengers. Tour group passengers are organized by travel agencies, and guided by tour conductors to take collective action. Accompany passengers are small groups constituted of families or friends in which close contact usually occurs. Individual passengers often walk alone, and the walking speeds are mainly decided by their own factors. The three kinds of passengers have obvious different walking characteristics in which valid contact time *t* in Eq. (4) is different.

Model modifications

SEIR model based on individual contacts

Rules of individual contacts based SEIR model for flu in terminal are improved as follow:

First, there were four mutually exclusive disease states during the diffusion, S (susceptible), E (exposed), I (infectious) and R (removed)[11].

Second, as to susceptible, who can be contaminated into exposed state, Eq. (4) determined the relationship between infected probability $F(t)$ and valid contact time *t* [12-13].

Third, the exposed could only remain latent during the residence or leave.

Fourth, infectious passengers might infect susceptible pedestrian into exposed during their stay in terminal.

Finally, removed were not capable of infecting or being infected.

Optimized social force model

The basic characteristics of social force model are as follows[14]:

Suppose a person *i* with weight m_i expects to walk at speed v_i^0 and direction $\vec{e}_i^{\,0}$. When accelerating to $\vec{v}_i$ in τ_i time, social force model argue that a certain distance with other pedestrians and walls needs to be maintained, which relates to velocity and could be modeled by psychological forces ($\vec{f}_{ij}$ and $\vec{f}_{iw}$).

Generally, pedestrian *i* tends to remain a certain distance with *j*. This psychology could be expressed by $\vec{f}_{ij}$:

$$\begin{cases} \vec{f}_{ij} = f_{ijn}\vec{n}_{ij} + f_{ijt}\vec{t}_{ij} \\ f_{ijn} = A_i \exp[(r_{ij} - d_{ij}) / B_i] + kg(r_{ij} - d_{ij}) \\ f_{ijt} = \kappa g(r_{ij} - d_{ij})\Delta v_{ji}^t \end{cases} \quad ...(5)$$

Where, the normal and tangential component of $\vec{f}_{ij}$ are comprised of f_{ijn} and f_{ijt}. $\vec{n}_{ij} = (n_{ij}^1, n_{ij}^2) = (\vec{r}_i - \vec{r}_j) / d_{ij}$ and $\vec{t}_{ij} = (-n_{ij}^2, n_{ij}^1)$ stand for the normal and tangential standardized vector pointing to *j* from *i*. A_i, B_i, k and κ are constants, while A_i denotes interactional strength among pedestrians, B_i represents psychological repulsion scope of pedestrians. The sum of radius of pedestrian *i* and *j* is expressed by $r_{ij} = r_i + r_j$ while d_{ij} is the centroid distance between pedestrian *i* and *j*. $\Delta v_{ji}^t = (\vec{v}_j - \vec{v}_i)\Delta \vec{t}_{ij}$, $g(x) = \begin{cases} 0, & x \le 0 \\ x, & x > 0 \end{cases}$ set the negative value to 0.

Similarly, the force $\vec{f}_{iw}$ between pedestrians and obstructions is given by:

$$\begin{cases} \vec{f}_{iw} = f_{iwn}\vec{n}_{iw} + f_{iwt}\vec{t}_{iw} \\ f_{iwn} = A_i \exp[(r_i - d_{iw}) / B_i] + kg(r_i - d_{iw}) \\ f_{iwt} = \kappa g(r_i - d_{iw})(\vec{v}_i \Delta \vec{t}_{iw}) \end{cases} \quad ...(6)$$

Where, the normal and tangential component of $\vec{f}_{iw}$ are comprised of f_{iwn} and f_{iwt}. The normal and tangential unit vector of obstruction w pointing to pedestrian *i* are represented by $\vec{n}_{iw} = (n_{iw}^1, n_{iw}^2)$ and $\vec{t}_{iw} = (-n_{iw}^2, n_{iw}^1)$. d_{iw} stands for the distance from centroid of pedestrian *i* to the surface of obstruction w. The rest parameters remain the same as Eq. (5).

Besides, the small groups with a certain connection will walk together. We think the close connections among small group needed to get special considerations. The force $\vec{f}_{iq}$ is employed to express these relations:

$$\begin{cases} \vec{f}_{iq} = f_{iqn}\vec{n}_{iq} \\ f_{iqn} = E_i \exp[(r_{iq} - d_{iq}) / F_i] \end{cases} \quad ...(7)$$

Where, $\vec{n}_{iq} = (n_{iq}^1, n_{iq}^2)$ denotes the unit vector pointing to pedestrian *i* from *q*. The distance from pedestrian *i* to *q* is represented by d_{iq} while E_i and F_i are constants. E_i, a positive number, stands for attraction intensity among accompanies. F_i represent attraction scope. The other parameters remain the same as Eq. (5).

Hence, the acceleration in moment *t* could be improved by kinematical equation given by Eq. (8) [15], where the first term denotes the self-driving force. The pedestrian accelerates or decelerates due to the joint forces of these four forces.

$$m_i \frac{d\vec{v}_i}{dt} = m_i \frac{v_i^0(t)\vec{e}_i^0(t) - \vec{v}_i(t)}{\tau_i} + \sum_{j(\ne i)} \vec{f}_{ij} + \sum_w \vec{f}_{iw} + \sum_q \vec{f}_{iq} \quad ...(8)$$

In this optimized social force mode, the three kinds of passengers have obvious different walking characteristics, among which the force $\vec{f}_{iq}$ is also slightly different. $\vec{f}_{iq}$ among accompany passengers is the biggest, so does the infection rate, next is tour group passengers then Individual passengers. The interactions among individuals of the tree kinds of passengers is shown by Fig 1, where, blue dots stand for tour group passengers, red dots represent tour guides, green dots denote accompany passengers, and purple dots indicate individual passengers.

The fusion of individual based SEIR model and social force model

Five simulative experiments are adopted to analyze the influential factors on influenza diffusion within a terminal. They are without considering any factors, considering super spreader only, considering age structure only, considering group behavior only and taking account of super spreader, age structure and group behavior at the same time respectively.

Terminal plane structure and passengers' flow setting

Fig 2. (a) gives the plane layout of

departure, where the entrances, check-in islands, security accesses, customs counters, inspection and quarantine windows, frontier inspection counters and boarding gates are offered. The activity area for domestic passengers is in the left side of this floor, while the right side of this floor is for international passengers. Fig 2. (b) shows the plane layout of arrival, in which the inspection and quarantine windows, frontier inspection counters, customs counters, baggage carousels and exits are offered.

The parameters of passengers' flow

In the five experiments, the percentages of susceptible, infectious, exposed and removed of the initial passengers are 81.2%, 8.8%, 3.1% and 6.9% in both arrival and departure. The cumulative number of passengers of arrival and departure are roughly 8700 in each experiment, among which the number of domestic passengers is approximately 3.2 times greater than international passengers.

The uniform distribution between 0.5 m/s and 1.0 m/s is employed as comfortable walking speeds of passengers. Meanwhile, distributions for domestic check in, international check in, security check, frontier inspection, customs and inspection and quarantine are uniform(60,180), uniform(120, 360), uniform(120,360), uniform(30,60), uniform(120,240) and uniform(50,80) respectively with units being second. In addition, passengers' arrival and departure time are determined according to airport flight schedule and number of passengers on each flight is assumed randomly distributed between 120 and 150.

Super spreader assumptions

Table 2 lists the number of assigned super spreaders.

Age structure assumptions

In recent years, the proportions of passengers in China civil aviation are 8.9% (under 19 years old), 64.5% (20 to 39 years old), 23.2% (40 to 59 years old) and 3.4% (above 60 years old)[10]. Together with the infection rate β_i $(0 \le \beta_i \le 1)$ in Table 1, this can be applied to obtain the impacts of age structure on influenza prevalence within the terminal.

Group behavior assumptions

As statistics shows, the percentages of above three classified passengers are 39.6%, 34.1% and 26.3% respectively[10]. Along with the variation of passenger psychological state, these four parameters, A_i, B_i, E_i and F_i, may change. Table 3 provides the assumptions about the three kinds of passengers.

RESULTS AND DISCUSSION

In the five experiments, the method coupling individual contacts based SEIR model and social force model is employed in each experiment to randomly model epidemic diffusion in the terminal. Each experiment runs 30 times.

The average number of infectious in departure experiment is detailed in Fig 3. (a). In the departure experiments, there are average 28.7 people infected by each super spreader, while 1.39 people contaminated by an ordinary infectious.

Whereas, there are average 16.7 people contaminated by each super spreader and 0.45 people get contaminated by common infectious people in arrival whose data is given by Fig 3. (b).

Furthermore, the total number of infectious passengers increases by 348 in departure all day while it only grows 34 in arrival considering super spreader. Consequently, we argue that super spreader impacts a great on prevalence in departure. Besides, the super spreader in domestic security zone has the highest infectious ability since there are 43.1 people effectively contaminated all day.

Table 4 provides the total number of infectious in departure and arrival. Compared with the experiment without considering any factors, the number of infectious persons in group behavior departure experiment increases 152, while is grows 163 in arrival. And the experiment reveals that group behavior plays an important role in arrival. Age structure shows a little impact on the spreads of influenza in the experiments. Probably because the age of China's civil aviation passengers mainly concentrate in 20 to 39 years old of which the infection rate is basically same.

Inspired by the result discussed above, some effective intervention measures, including terminal ventilation, disinfection and reasonable partition, need be implemented to control influenza transmission in the terminal. Furthermore, opening more service resources as earlier as possible would no doubt shorten residence time, as to reduce the valid contact probability. Moreover, test the

Table 1. The infection rate of Susceptible in different age groups

Age groups(years old)	<19	20~39	40~59	>60
Infection rate (β_i)	β_1=13.23%	β_2=14.30%	β_3=13.01%	β_4=9.26%

Table 2. Number of assigned super spreaders

Scene	Super spreader
Departure	Domestic check-in×2, Domestic security check×1, Domestic boarding gate×2, International security check×1, International check-in×2, Customs×1, Frontier inspection×1,
International	boarding gate×2

Table 3. Group behavior experiment's assumptions

Classification of passengers	Scale	A_i	B_i	E_i	F_i
Tour group passengers	uniform (15,40)	0.3	1.2~3.6 m	-2.1	0.45~1.2 m
Accompany passengers	uniform (2,14)	0.3	1.2~3.6 m	-1.2	0~0.45 m
Individual passengers	1	0.3	1.2~3.6 m	0	1.2~3.6 m

Table 4. The number of Infectious in departure and arrival

	Without considering any factors	Considering super spreader	Considering age structure	Considering group behavior	Considering all factors
Departure	1067	1415	1047	1219	1528
Arrival	342	376	330	505	571

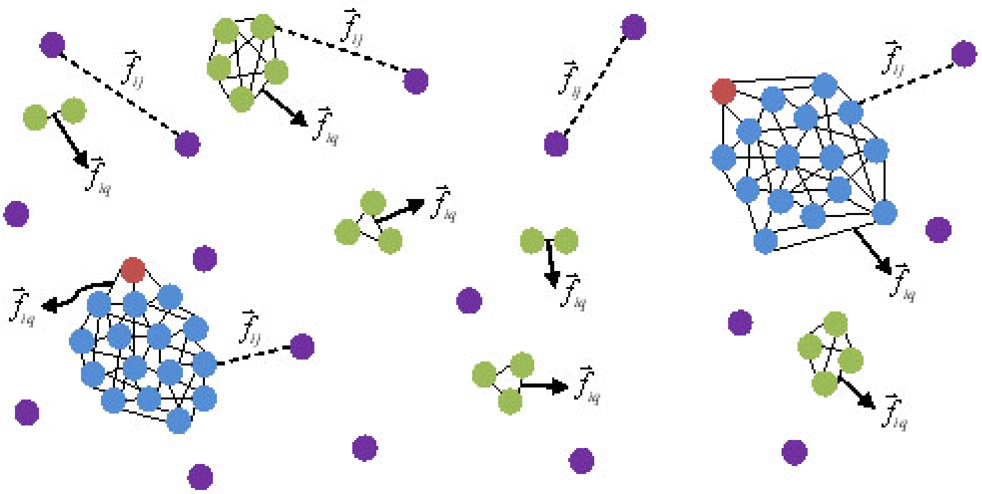
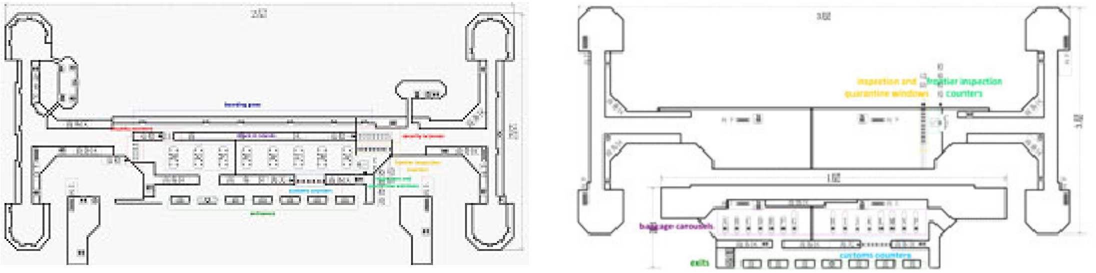
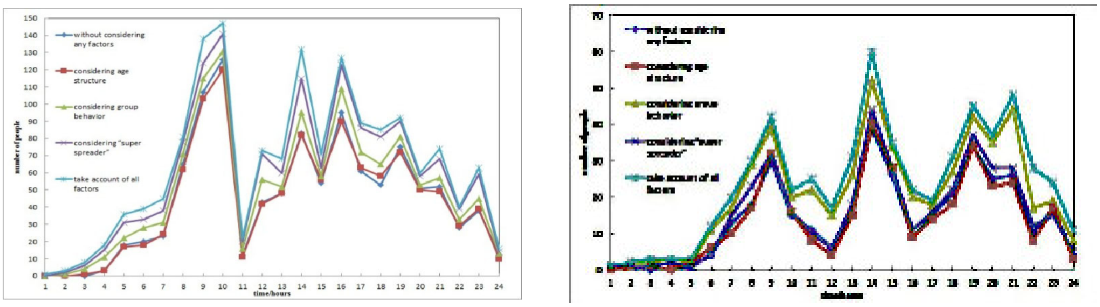


Fig. 1. The interactions among individuals of the tree kinds of passengers



(a) The plane layout of departure (b) The plane layout of arrival

Fig. 2. The plane layout of departure floor



(a) Departure (b) Arrival

Fig. 3. The number of Infectious in departure and arrival all day

physical condition of staff regularly to stop him becoming a super spreader in departure. Once a staff shows infected symptoms, other staff should replace him immediately. Besides, endemic area isolation is used for infectious groups in arrival. Special gate, inspection and quarantine windows, frontier inspection counters, baggage carousels, customs counters and exits are assigned for the affected flight.

CONCLUSIONS

In the simulations, the influences of super spreader get studied with the assignment of several super spreaders. And the behaviors of large crowd get micro-modeled with the utilization of improved social force model in which the consideration of the impacts from other pedestrians, environment and close accompanists raised the accuracy of key parameters in individual contact based SEIR.

1. There were more infections in departure than that in arrival. Super spreaders impacted a lot in departure, while group behavior imposed a great infection in arrival. Besides, age group shows a little effect in both departure and arrival.
2. In departure, staffs should get due attention and regular physical condition test in order to stop super spreader coming into being. In arrival, endemic area isolation and should be employed. Other intervention measures, such as terminal ventilation, disinfection and reasonable partition and opening more service resources as earlier as possible, should be adapted to the arrest influenza development in both departure and arrival.
3. This method possessed the capability of quantitatively describing the influenza prevalence process, analyzing influences of concerned factors, as well as proposing effective intervention strategies.

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