MEMORANDUM

Date: October 26, 2018

From: *Jingying Hu*

To: Surveillance and Response Support, European Centre for Disease Prevention and Control

Subject: Modeling the H3N2 influenza epidemic on Elba

Introduction, purpose and approaches

The small Tuscan island of Elba, population 32,000, is threatened by a particular deadly strain of flu. However, the spreading of the flu is affected by many variables, including the number of healthy people, the sick, the immuned as well as free riders, people who are not willing to be vaccinated but they have less chance of encountering a sick person if lots of people are gertting vaccinated. Drawing on our knowledge of chemical kinetics and reactor design, we propose the network of elementary "reactions" below to model how a contagious disease will spread among the hapless residents of Elba. Also, based on the chemical kinetic equations in Table 1, we can use different models to simulate the spreading pattern with different parameters, including the continuous-variable deterministic model and the discrete-variable stochastic model.

Discussion and conclusion

People can become immune by recovering from the sickness or being vaccinated. As in Fig. 1, if there's no vaccine available, both of continuous and stochastic model predict that the number of sick people will quickly reaches its peak value before within 30 days. However, if vaccine is initially available and replenished as in Fig. 2, all the curves look more placid than in fig. 1 and the number of sick people reaches a smaller peak value. However, compared with Fig. 2, increasing of the number of "free riders" doesn't lead to a significantly change by stochastic model in Fig. 3. Also, if the day for providing additional vaccine after 30 or 40 days, there's no obvious difference between them when predicted by stochastic model as in Fig. 5 and 6. Since it's impossible to find the probability of each free riders encountering a sick person, the time when the number of sick people will reach its peak is very fickle. Minor changes between these figures are acceptable. If additional vaccine is provided earlier 10 days after the flu breaks out, the spreading process is facilitated and quickly enters the sick people decreasing stage as in Fig. 4, but the death toll doesn't change. Although the continuous model predicts that the sooner the additional vaccine is provided, less people will die of the flu. From the prediction of stochastic model, it seems that additional vaccine provided later can't efficiently help decrease the death toll. This is because the number of healthy people is decreasing while k4 is rather small as in Table.1, the probability of people get vaccinated after additional vaccine is provided is smaller than initially when there is a large number of healthy people. There is also related evidence in Fig.6, if initially the number of vaccine is sufficient to support the whole population, the death toll after 120 days is likely to range from 300 to 500 as shown in Fig. 8.

To conclude, the expected number of deaths depend more strongly on initial number of vaccine than variables related to additional vaccine and free riders.

Attachment

Event ("reaction")	Rate (events/day)	Description
$H + S \xrightarrow{k_1} 2S$	$r_1 = k_1 n_S n_H$	Healthy person becomes sick through contact with a sick person
$F + S \xrightarrow{k_1} 2S$	$r_2 = k_1 n_S n_F$	Free rider becomes sick through contact with a sick person
$S \xrightarrow{k_2} I$	$r_3 = k_2 n_S$	Sick person recovers and is now immune
$S \xrightarrow{k_3} D$	$r_4 = k_3 n_S$	Sick person dies
$H + V \xrightarrow{k_4} I$	$r_5 = k_4 n_H n_V$	Healthy person is immunized by vaccination

Table 1 elementary reactions under the flu spreading model in Elba, k_1 = 1.76e-05, k_2 = 0.1, k_3 = 0.01, k_4 = 3.52e-06.

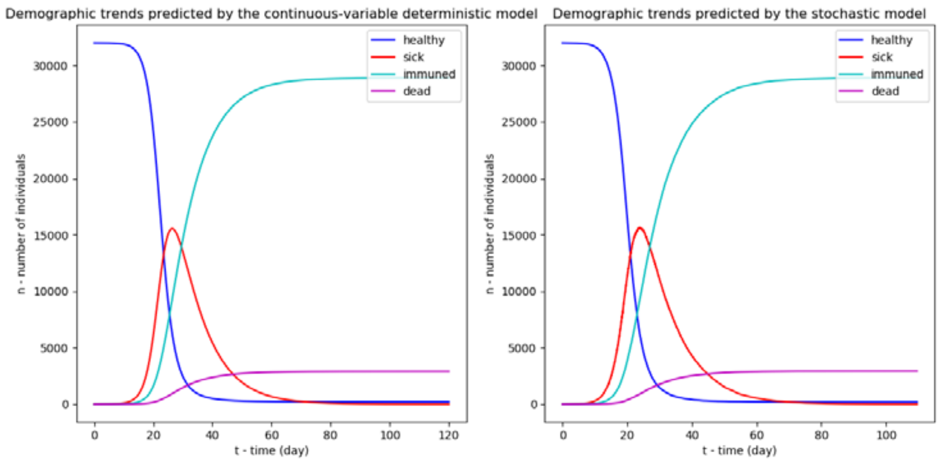

Fig. 1 Population change in 120 days if there is no vaccine available, no free rider and only one sick person initially.

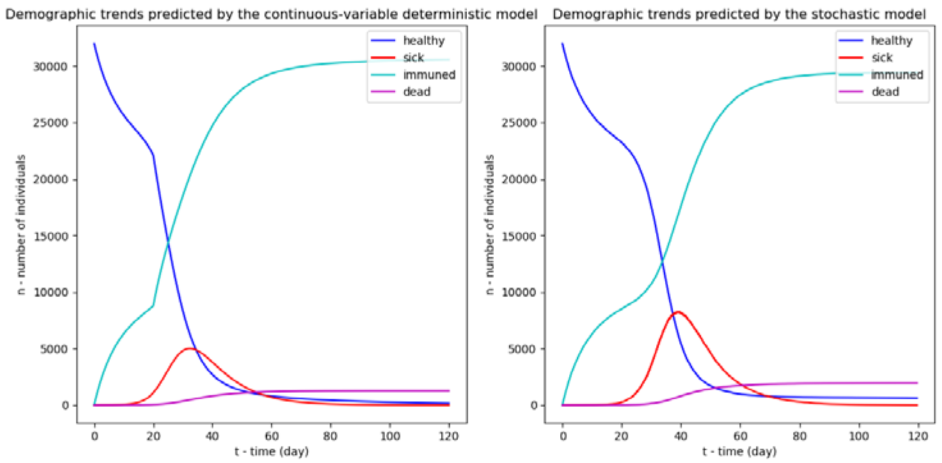

Fig. 2 Population change in 120 days if there are 10,000 doses of vaccine initially available, 15,000 additional doses of vaccine available on day 20 and no free rider.

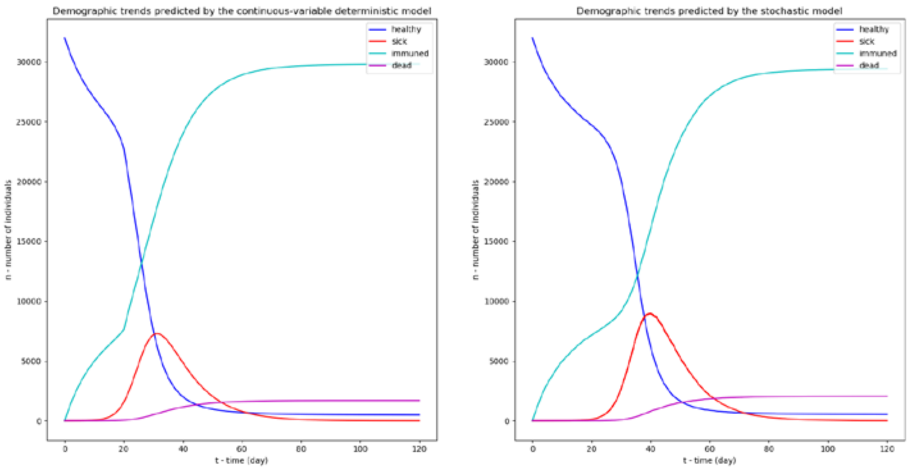

Fig. 3 Population change in 120 days if there are 10,000 doses of vaccine initially available, 15,000 additional doses of vaccine available on day 20, and if 30% of the residents refuse to be vaccinated (9600 free riders).

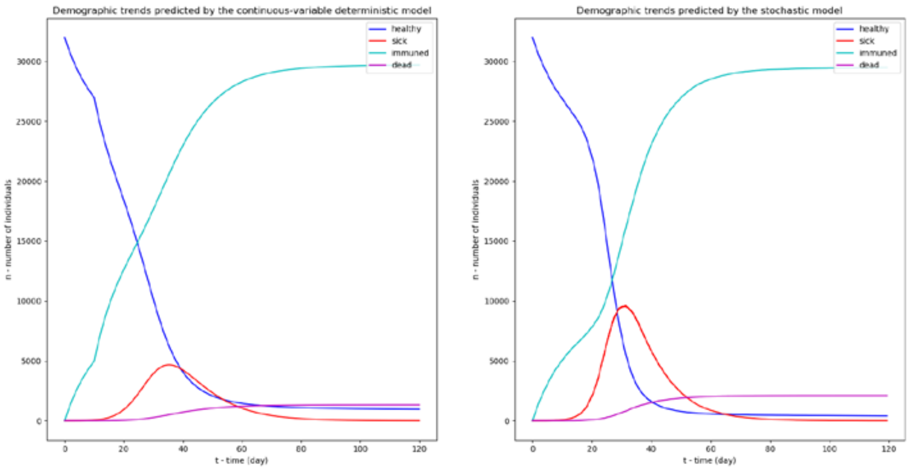

Fig. 4 Population change in 120 days if there are 10,000 doses of vaccine initially available, 15,000 additional doses of vaccine available on day 10, and if 30% of the residents refuse to be vaccinated (9600 free riders).

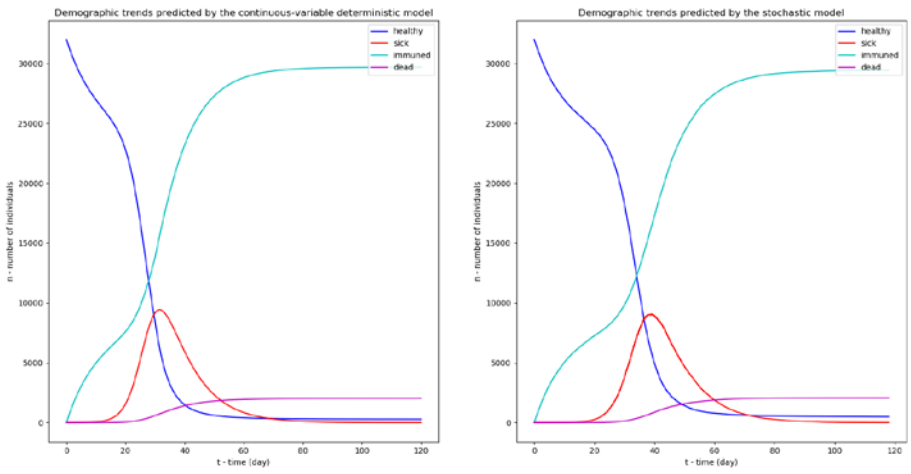

Fig. 5 Population change in 120 days if there are 10,000 doses of vaccine initially available, 15,000 additional doses of vaccine available on day 30, and if 30% of the residents refuse to be vaccinated (9600 free riders).

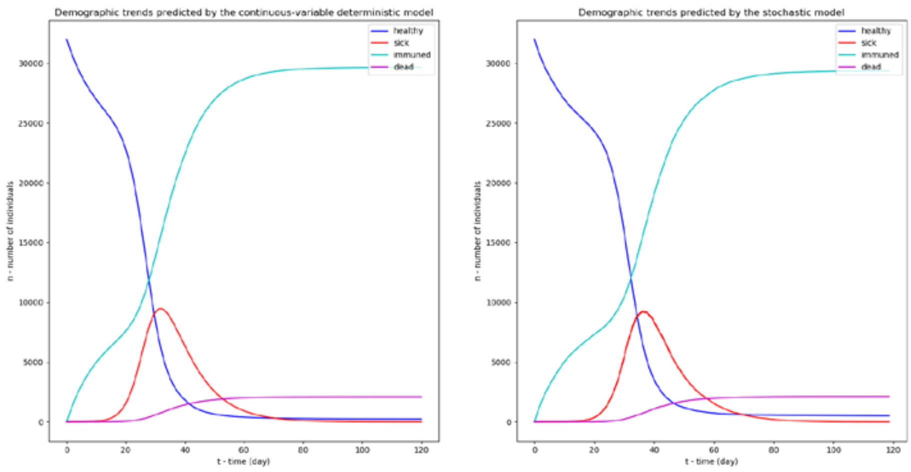

Fig. 6 Population change in 120 days if there are 10,000 doses of vaccine initially available, 15,000 additional doses of vaccine available on day 40, and if 30% of the residents refuse to be vaccinated (9600 free riders).

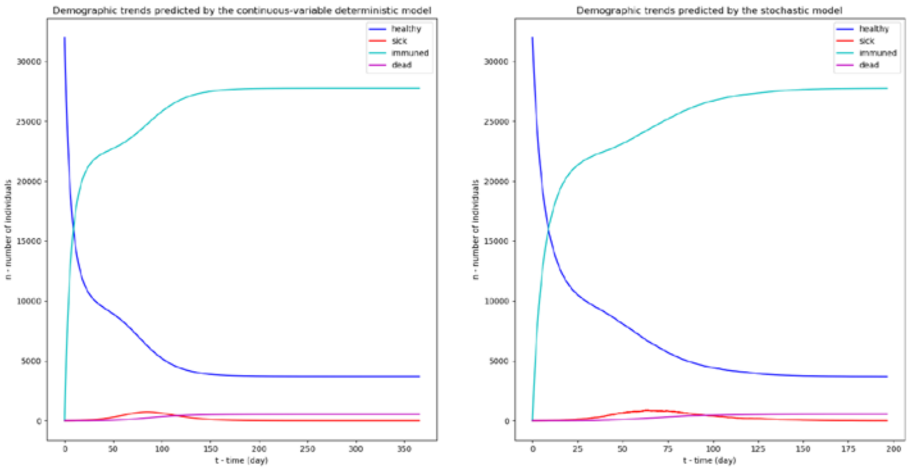

Fig. 7 Population change and expected death toll within 200 days if there are 9600 free riders and 50,000 doses of vaccine are available at time zero.

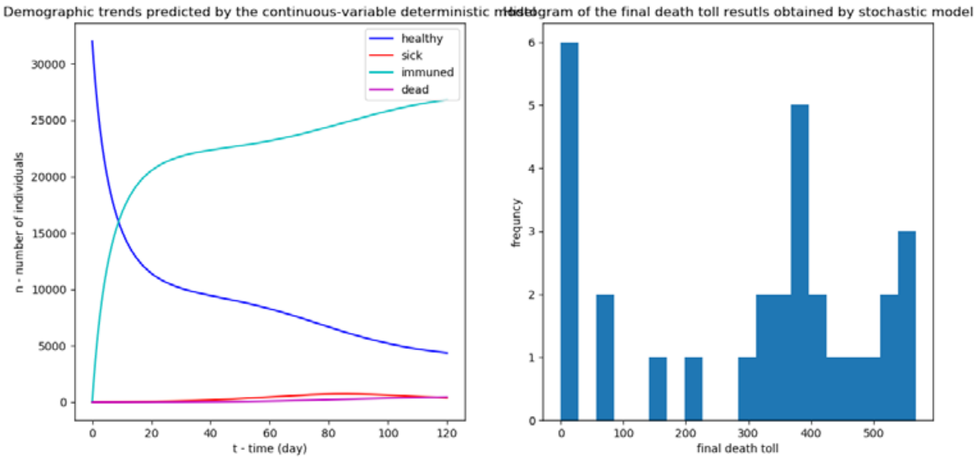

Fig. 8 Population change and expected death toll in 120 days if there are 9600 free riders and 50,000 doses of vaccine are available at time zero (repeat 30 times).

Reference

Rathman, Jim, CBE 5790 Modeling and Simulation in the Ohio State University, autumn 2018.