

THE ROLE OF MATHEMATICS IN CONTROLLING INFECTIOUS DISEASE TRANSMISSION: A LESSON FROM CIKELET CASE STUDY

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Introduction

Despite recognized as an abstract science, mathematics has proved to be useful in helping to solve many problems arising in daily life and problems from other disciplines, such as industrial, environmental, and biological sciences. The inter-relations between mathematics and other disciplines have not only giving benefits to the disciplines served by mathematics, but in many cases, there are also fruitfulness to mathematics itself. There are some mathematical concepts and theories inspired from these inter-relations. Sometimes the intimate connection between mathematics and other discipline gives rise to a new discipline, such as in the case of mathematical epidemiology.

Earlier works in mathematical epidemiology dated back to eighteenth century, when Bernoulli used a mathematical method to evaluate the effectiveness of the techniques of inoculation against smallpox, with the aim of influencing public health policy. He showed that, if the inoculation is universal, the techniques could increase the number of survivors per year or increase the average life expectancy. Further results in mathematical epidemiology can be seen in many literatures, in which most authors postulated that the course of an epidemic depends on the rate of contact between susceptible and infected individuals, termed as the *mass action principle*. Meanwhile, a medical doctor, Sir Ronald Ross in the early twentieth century identified the main factors in malaria transmission and calculated the number of new infection. His analysis ended up to a conclusion that no need to eradicate all of the mosquitoes to eradicate malaria, because there exists a *critical density of mosquitoes*, below which the disease will vanish, this is known as the *mosquito theorem*, or the theory of *critical level of eradication*. This result was formalized and generalized by Kermack and MacKendrick about a decade later. Similar finding were attributed to Macdonald in the middle of the twentieth century who introduced the concept of *basic reproduction rate* and defined in a more plausible manner by Diekmann and Heesterbeek (2000) as the expected number of secondary cases per primary case in a 'virgin' population.

In this paper we give an example of the applications of mathematics in understanding and controlling a newly emerging and novel disease, avian flu (AI), in Dusun Tipar (Tipar Village) within the district of Cikelet (Garut, West Java). This hilly village covers the area of approximately 70 ha with relatively sparse human and chicken populations of about 2,000 and 10,000, respectively. The study of AI transmission in Tipar Village is important due to the following reasons. The outbreak of AI in this village is the first endemic at such scale and an action to prevent a more devastating outbreak should be taken. There was transmission from chicken to human and the phenomenon is not fully understood. Similar case may happen in other places, since many villages in West java are typically similar to Tipar in many respects. The villagers usually keep some backyard chickens, in which the chickens free from custody during the day time for foraging and going back to their nest underneath the owner's house in the evening.

Chronologically, a rapid transmission of AI in Tipar is as the following. On April 2006, one person bought few chickens from central market for village festivity. Two or three of them died on the way to the village, and were discarded somewhere near the village border. In the next following days, few chickens died without reason. No one has reported this chronological incident in the newspapers. Nevertheless, it was reported that the outbreak occurred around the end of June 2006 and lasting for more than one month, with 11 human cases of Avian Influenza reported (five died and six suspected). Eradication and other necessary actions were done following the outbreak.

The outbreak of AI in Tipar village has heightened national concerns about the weakness of the country to prevent a pandemic. Among questions that need to be answered, in terms of understanding and controlling the disease, are as the following.

- How to explain in simple scientific terms about the spread and the disappearance of AI?
- Are there any easy indicators to identify possible endemics before infection starts to occur?
- Is total eradication necessary? If not, what are the consequences?
- With possible adaptation of virus in human body, what are the consequences?
- How to find an affordable effective control strategy which is realistic to be implemented?

To address these questions is rather difficult due to the lack of data. Even if the data is available, it is far from accurate. In many cases, measurement is impossible to be done and information is scattered and difficult to access. Presumably, this is simply because of a limited government budget in health sector. In this paper we propose an approach using mathematical model to address those issues.

Results / Discussion

We model AI transmission in a chicken (traditional) farms in which we assume that the farms are spread through out the region, with free contact among chickens within the farm. The village is divided into six separated sub-regions in which there is no direct contact between chicken from different sub-region. The spread of infection from one sub-region to the others may come from indirect contact such as from air or from water. Recruitment rate is assumed to be constant. There are two types of death, i.e. natural death and death from AI virulence. The contact among individuals is random and harvesting is done and distributed proportionally both to susceptible chickens and (asymptomatically) infected chickens. The transmission mechanism in each sub-region is depicted in Figure 1. Differential equations for a simple case are devised to express this mechanism. The form is similar to the equations in Figure 5, but without human compartments. Analysis of the disease transmission was done by utilizing the concept of *basic reproduction number*. Simulation is then carried out by applying some known parameters to obtain some inferences and interpretations.

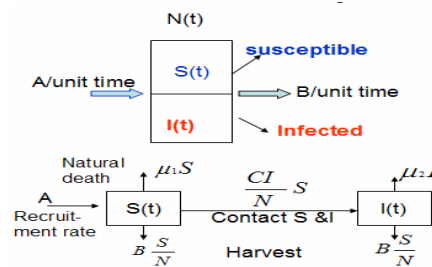


Figure 1

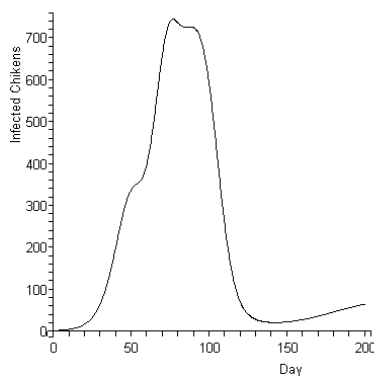


Figure 2

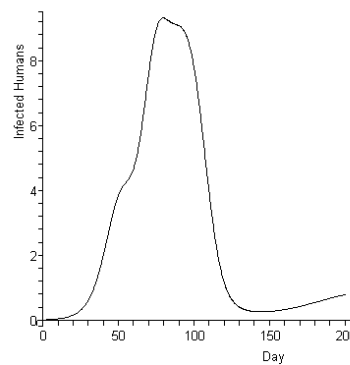


Figure 3

Figure 2 shows the dynamics of AI in chicken population. Initially there are 10,000 healthy chickens when an infectious chicken introduced into the farm. Within approximately 80 days the disease has successfully invaded all the farms and reached the peak. In this simulation we assume that there is no intervention to contain the AI. The figure shows that the disease does not fade away. This partially might be due to the relatively high recruitment of the healthy chickens and low harvest (A and B , respectively, in the R_0 expression below).

Since infection in human is identified, we then include disease transmission to human. We assume that there is no separation between chicken population and human population. Transmission occurs from chickens to human and not the other way around. A high risk group of people has a “close contact” with chickens in daily basis, and transmission of AI from human to human occurs only within cluster. As an illustration, a schematic diagram of the transmission, if there is only one region considered, is given in Figure 4 with the corresponding mathematical equations in Figure 5.

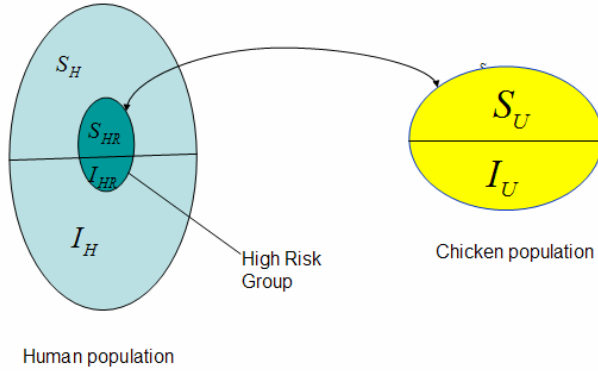


Figure 4

$$\frac{dS_{HR}}{dt} = K_1 - k_1 S_{HR} I_U - \mu_H S_{HR}$$

$$\frac{dI_{HR}}{dt} = k_1 S_{HR} I_U - \eta_H I_{HR}$$

$$\frac{dS_H}{dt} = K_2 - k_2 S_H I_{HR} - \mu_H S_H$$

$$\frac{dI_H}{dt} = k_2 S_H I_{HR} - \eta_H I_H$$

$$\frac{dS_U}{dt} = A - \frac{cI_U}{N_U} S_U - \mu_1 S_U - B \frac{S_U}{N_U}$$

$$\frac{dI_U}{dt} = \frac{cI_U}{N_U} S_U - \mu_2 I_U - B \frac{I_U}{N_U}$$

Figure 5

In this case, the basic reproduction number for the transmission of the disease is

$$R_o = \frac{c}{\mu_2 + \mu_1 / (A/B - 1)}. \text{ The disease will endemic only if this number is greater than one. Figure 3}$$

shows the resulting graph of infected human from this model. It reveals that the dynamics of infected human population is behaving like the infected chicken population. Hence, endemic in chicken population implies endemic in human population. Moreover, it also implies that treatment is needed to stop the AI transmission. Iwami et al. (2007) show that if there is no action to stop the spreading of AI, there is a possibility that there will be a mutant of AI with increasing transmissibility (Fergusson et al., 2005), spreading from human to human, which eventually may cause a pandemic. The effectiveness of some containment strategies have been investigated for the case of rural Southeast Asia regions (Longini et al. 2005) and Worldwide (Colliza et al., 2007). Poultry vaccination, culling, or combinations of both are among the strategies that have proven to be effective (Van der Goot et al., 2005; Webster and Hulse, 2005), which to some extent has been applied in the Tipar case. We believe that the rapid disappearance of the disease might be due to the presence of health authority intervention, in this case poultry eradication.

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