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Avian Flu Model

MAT3395

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Objectives

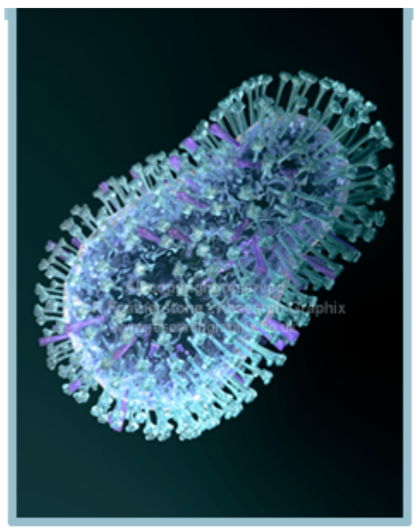
-Estimate the size of an outbreak if a shift occurred in the disease

-determine if quarantine would be as effective as it was with SARS in 2002

-estimate the number of people who would need antiviral treatment to control an epidemic in a city like Toronto

Background

Avian flu is caused by a particular strain of the influenza virus, Avian Influenza-A, also known as the H5N1 virus.



Avian Influenza is very common in wild birds, which carry the virus in their intestines but don't actually get sick. These carriers tend to infect domesticated birds living in crowded unsanitary conditions (poultry in Asia is a good example); these are the birds that show symptoms and infect humans. It is very rare among humans: of all of the outbreaks infecting millions of birds, only 413 confirmed cases have been documented as of 30 March 2009. The vast majority of cases can be traced back to direct contact with the excretions and secretions of infected birds, so the disease doesn't seem to be contagious among humans. However, of the 413 cases there have been 256 deaths, so if the disease did undergo a shift there would be cause for great concern.

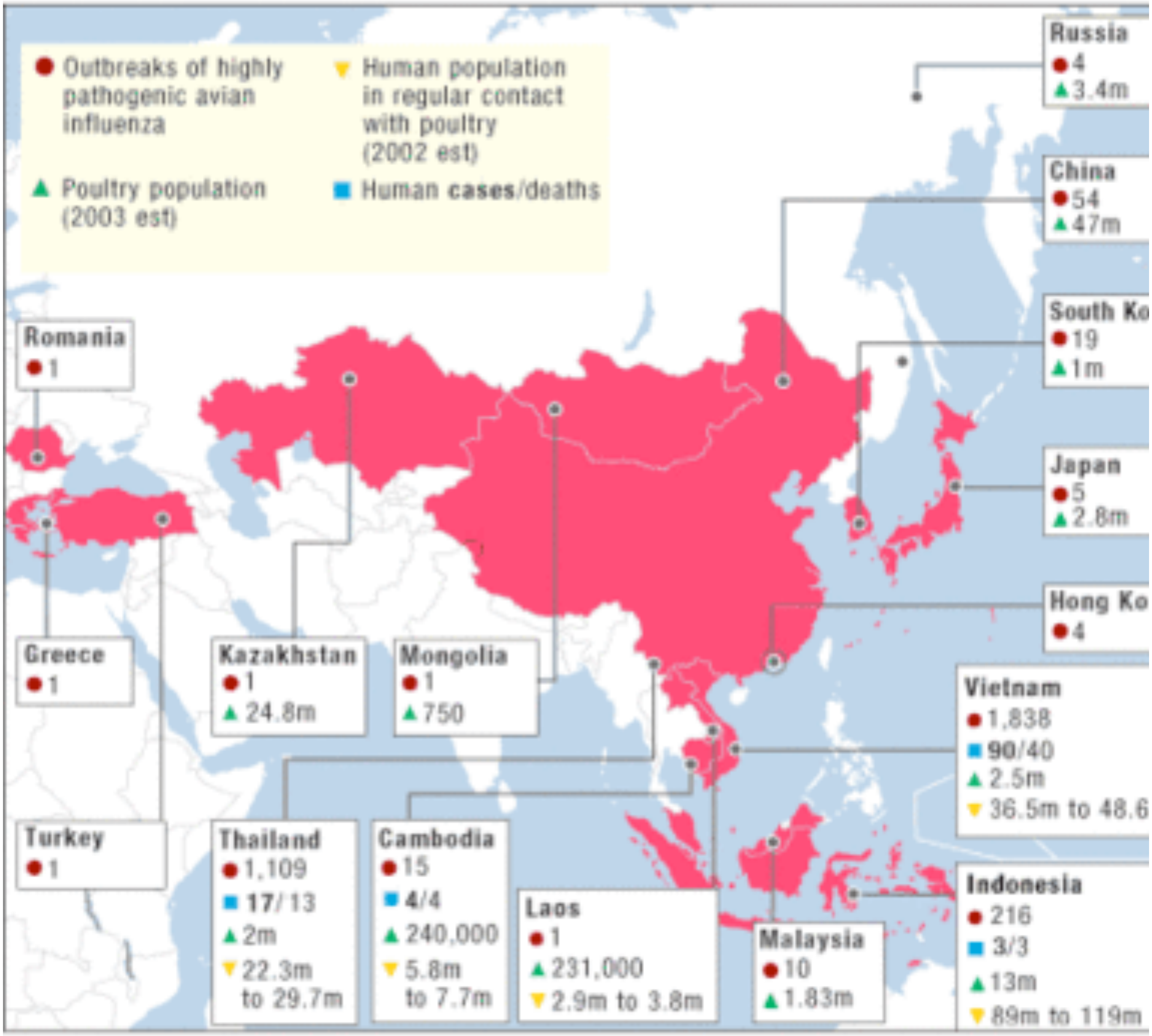
The symptoms of Avian Flu start as regular flu-like symptoms (fever, cough, sore throat, aches and pains) but can develop into eye infections, pneumonia, severe respiratory diseases and other life-threatening complications. Oseltamavir is the antiviral medication recommended by the WHO for Avian flu, but its efficiency is unknown because further studies are required.

Cumulative Number of Confirmed Human Cases of Avian Influenza A/(H5N1) Reported to WHO

30 March 2009

Country	2003		2004		2005		2006		2007		2008		2009		Total	
	cases	deaths	cases	deaths	cases	deaths	cases	deaths	cases	deaths	cases	deaths	cases	deaths	cases	deaths
Azerbaijan	0	0	0	0	0	0	8	5	0	0	0	0	0	0	8	5
Bangladesh	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0
Cambodia	0	0	0	0	4	4	2	2	1	1	1	0	0	0	8	7
China	1	1	0	0	8	5	13	8	5	3	4	4	7	4	38	25
Djibouti	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
Egypt	0	0	0	0	0	0	18	10	25	9	8	4	9	0	60	23
Indonesia	0	0	0	0	20	13	55	45	42	37	24	20	0	0	141	115
Iraq	0	0	0	0	0	0	3	2	0	0	0	0	0	0	3	2
Lao People's Democratic Republic	0	0	0	0	0	0	0	0	2	2	0	0	0	0	2	2
Myanmar	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
Nigeria	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	1
Pakistan	0	0	0	0	0	0	0	0	3	1	0	0	0	0	3	1
Thailand	0	0	17	12	5	2	3	3	0	0	0	0	0	0	25	17
Turkey	0	0	0	0	0	0	12	4	0	0	0	0	0	0	12	4
Viet Nam	3	3	29	20	61	19	0	0	8	5	6	5	2	2	109	54
Total	4	4	46	32	98	43	115	79	88	59	44	33	18	6	413	256

Avian flu outbreaks



Sources: FAO; OIE; WHO; news agencies

Our Model

We assumed: -birds are only infected by other birds

-both birds and humans can die from this disease

-quarantine and culling rates can change

-birds don't recover

$B_S' = \lambda^B - \mu^B Bs - \beta^B B_I B_S$

$B_I' = \beta^B B_I B_S - \mu^B B_I - \gamma^B B_I - \tau\,(B_I)$

$H_S' = \lambda^H - \mu^H H_S - \beta^{BH} B_I H_S - \beta^{HH} H_I H_S$

$H_I' = \beta^{BH} B_I H_S + \beta^{HH} H_I H_S - \mu^H H_I - \gamma^H H_I - \nu^I H_I - q(H_I)$

$H_R' = \nu^I H_I + \nu^Q H_Q - \mu^H H_R$

$H_Q' = q(H_I) - \mu^H H_Q - \nu^Q H_Q$

Where: - β's are transmission rates

-τ is culling, a function of the number of infected birds

-ν's are recovery rates

-γ's are death rates due to the disease

-q is quarantine, a function of the number of infected humans

This model is quite complicated. After doing some research, we found that each human case has resulted from exposure to particular infected birds, and that these are very rare. Therefore, the overall numbers of infected birds do not make a large difference. Any outbreak of avian flu we thought would die out before a new transmission from bird to human occurred. We felt that getting rid of the bird classes would help simplify our model and make examining the human implications much easier.

Here is our revised model; we have added a dead class which we forgot to add to the original one. This class will enable us to see the overall effects of quarantine and treatment in more detail.

- $S' = \lambda - \mu S - \beta SI$
- $I' = \beta SI - \mu I - \gamma I - \nu I - qI$
- $R' = \nu I + \nu Q - \mu R$
- $Q' = qI - \mu Q - \nu Q - \gamma Q$
- $D' = \gamma I + \gamma Q$

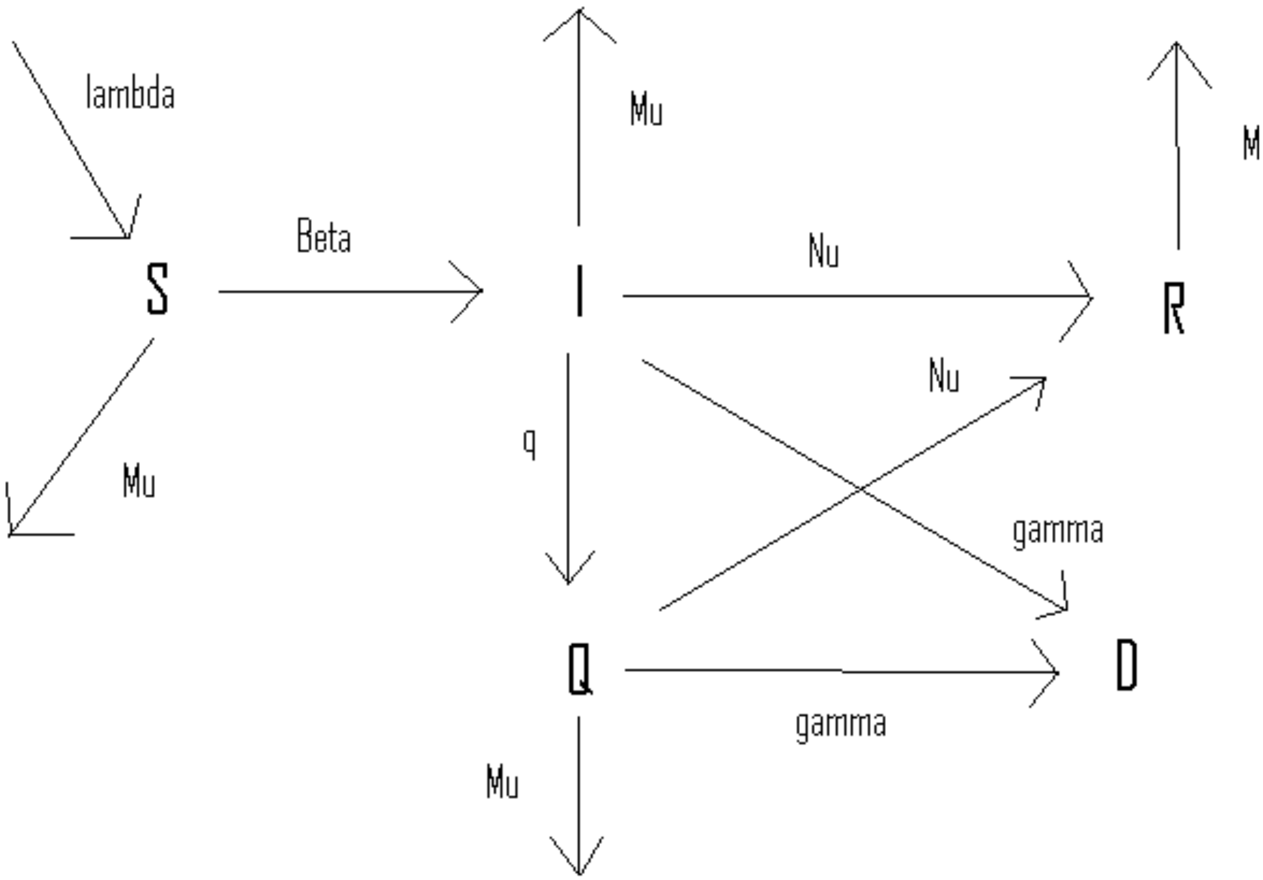
This model gives the following R_0 and R_{0E} values respectively:

$$\frac{\beta S}{\mu + \gamma + \nu + q}$$

$$\frac{\mu \beta S}{\mu(\mu + \gamma + \nu + q) + I\beta(\mu + \gamma + \nu + q)}$$

Because influenza outbreaks move quickly, equilibrium would probably only occur once all infected people died or recovered (I=0). This would mean that R_0 and R_{0E} would be equal.

Flow Diagram



Estimation of our Parameters

Susceptibles: 5.5 million, the population of the GTA

Initial infected: we imagined 10 newly infected farmers spending the day in downtown Toronto.

Infection rate: for the original strain we estimated 1/10,000,000 but ten times as strong for a shifted virus

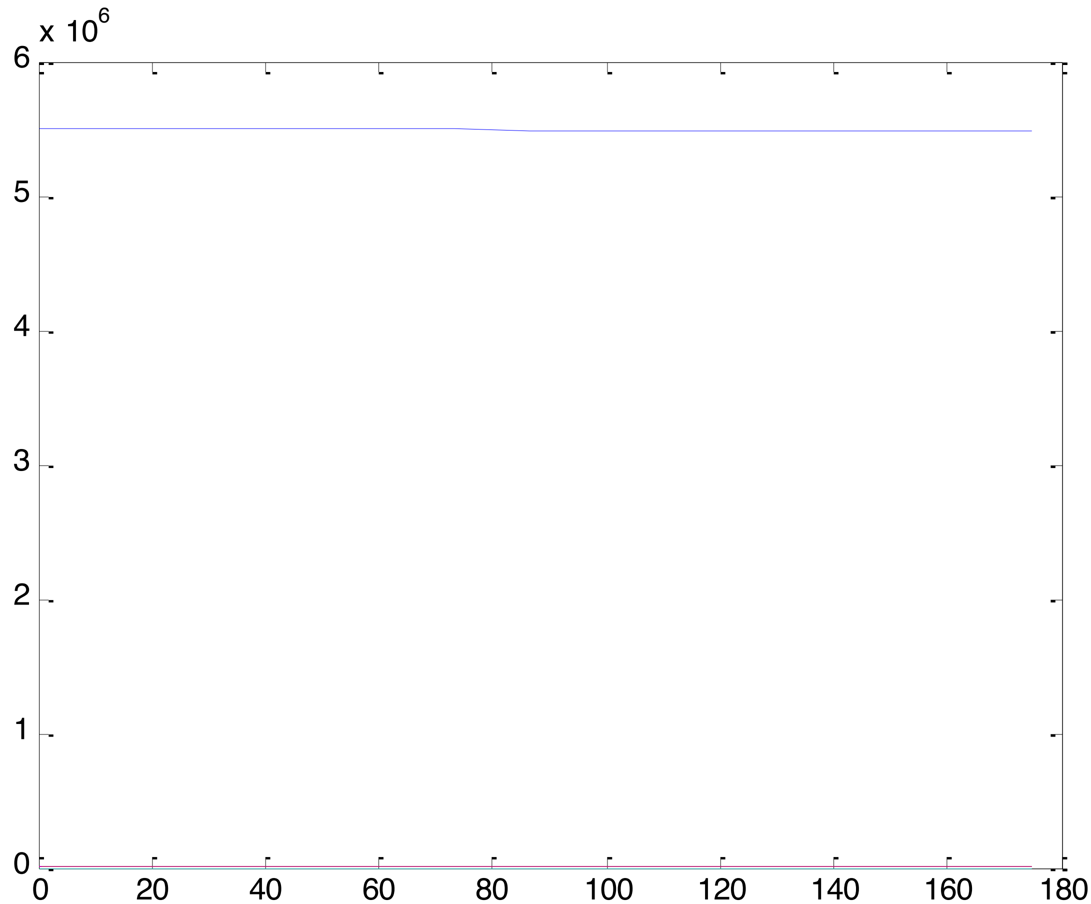
Quarantine rate: because of the efficiency of Tonroto's response to SARS, we think that a value of 0.25 is fair. This would mean that city officials would round up one quarter of the total infected people each day for quarantine.

Birth and Background Death rates: we took the census values for Canada, divided by 365 days and then multiplied those by the appropriate classes. These would be 155 births per day total and 1/47963 as a background death rate, multiplied by the population in each class.

The original survival rate is 1 – 256/413 = 38%, according to WHO data. We estimated that half of this 38% was due to natural recovery and half due to antiviral treatment: not all people in Southeast Asia have access to these drugs. When our natural recovery rate is 0.02, then 18% recover within ten days and this fits our data. When our death rate is 0.06, then 46% will die within ten days, and this also fits our data. We estimated the recovery rate with treatment to be higher in Toronto than in Asia, since Canada has more resources at its disposal. For a recovery rate of 0.10, 65% recover within ten days and we feel comfortable with this.

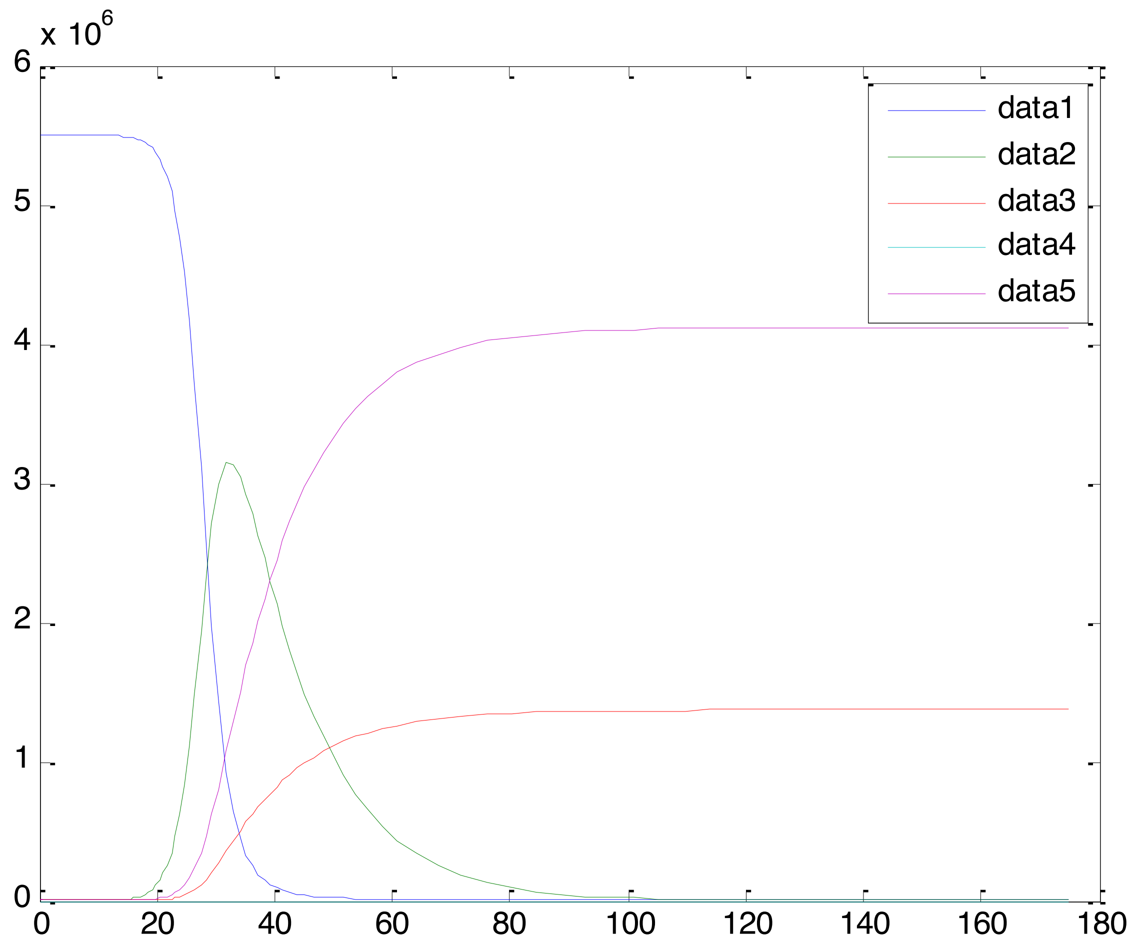
Time Series Simulations

Current strain of Avian Flu: q = 0, nu = 0.02 beta = 10^{-8}



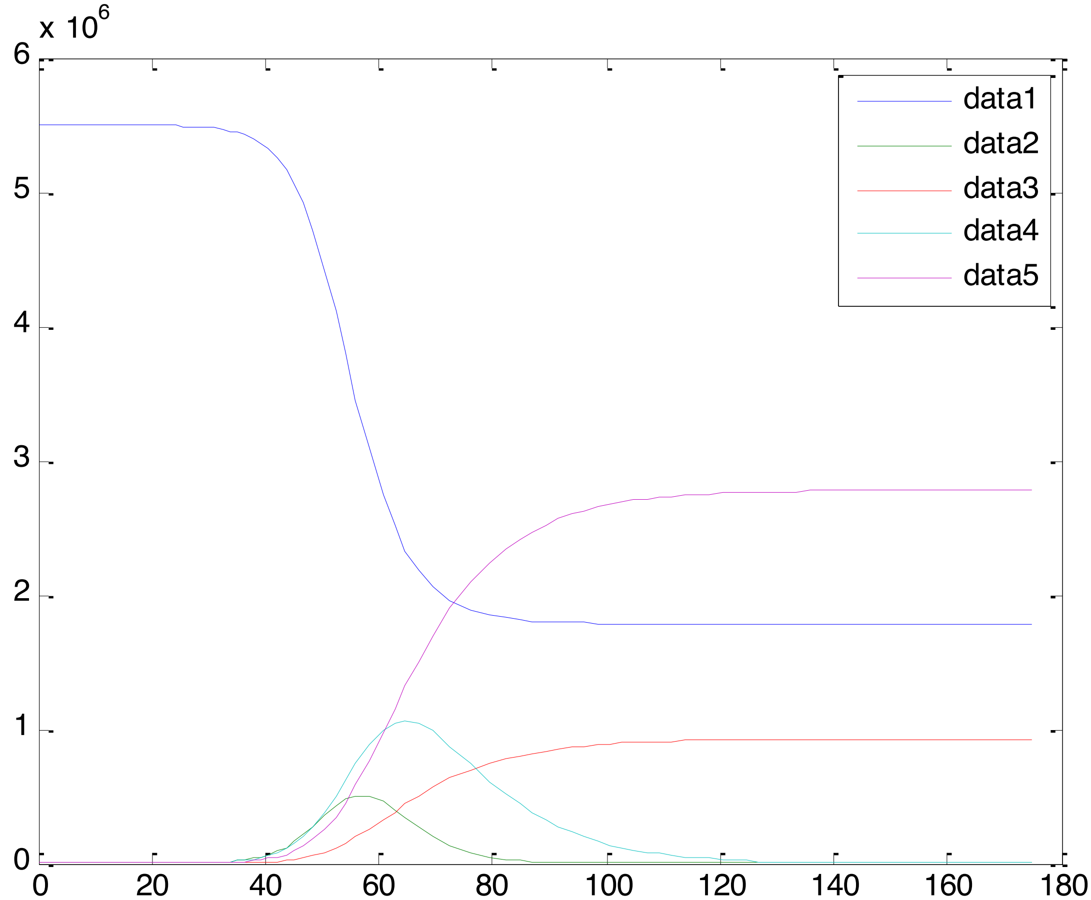
We can see that when the value of beta is still low, like it is now for avian flu, the disease never takes hold. The number of susceptibles decreases only very slightly, and the infected class stays at zero because the recovery rate is large enough to keep it that way.

Shifted virus with no counter-measures: q = 0, nu = 0.02 beta = 10^{-7}



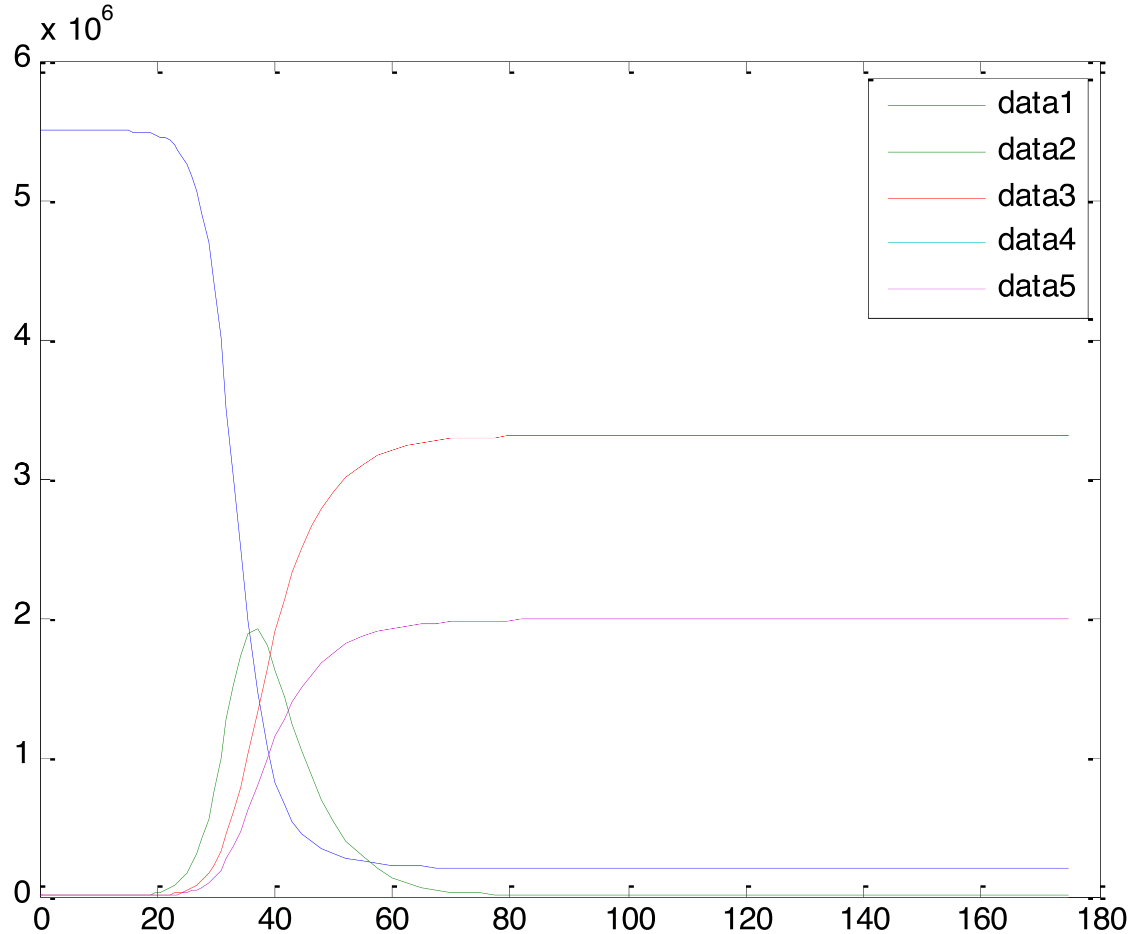
When the virus shifts and beta is increased, the disease does take hold with catastrophic consequences. Within fifty days, all of the population has been infected. Within one hundred days over four million are dead from the disease, and about 1.3 million have recovered.

<u>Shifted virus with quarantine</u>: q = 0.25, nu = 0.02 beta = 10^{-7}



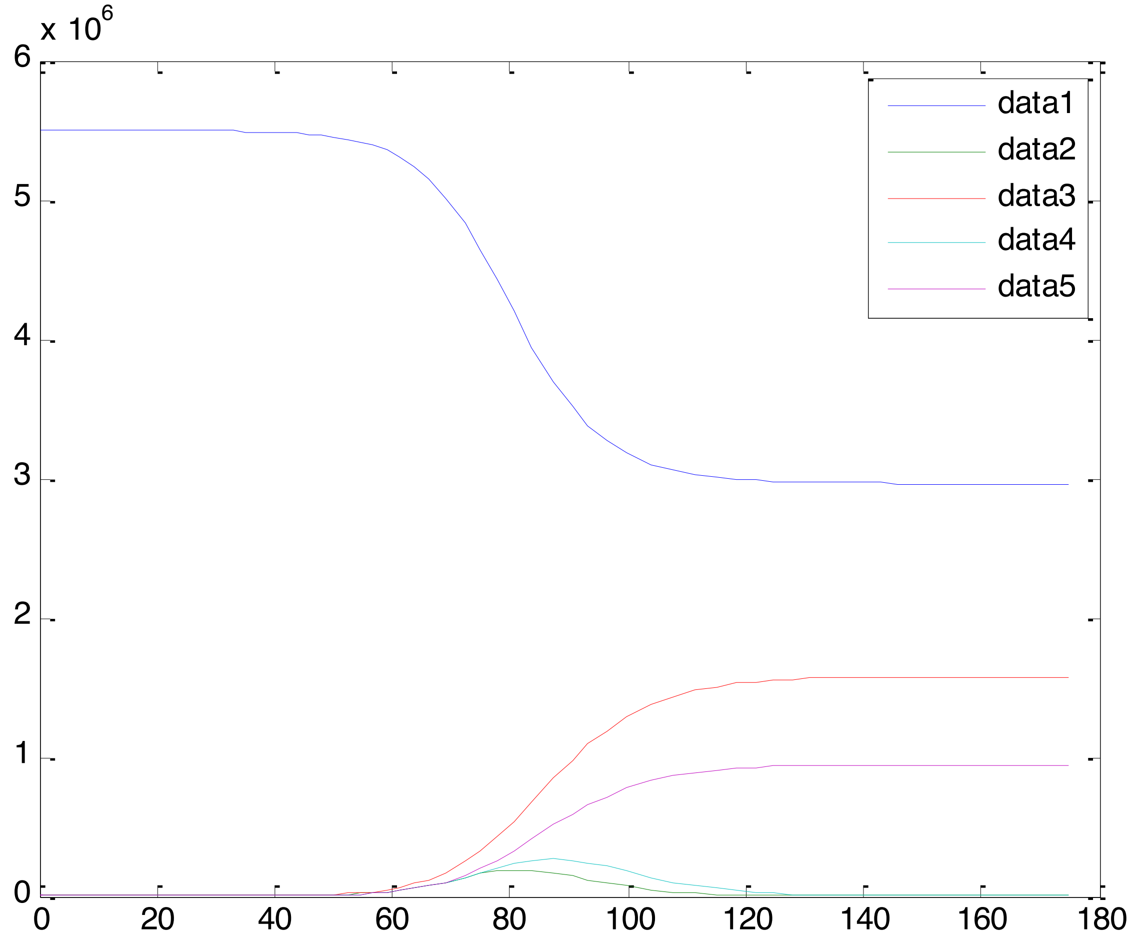
When quarantine is added to the model, more than one million lives are saved. By the seventieth day, about one million people have been quarantined, and then this number goes to zero by the one hundred and twentieth day as people die or recover. The disease is still lethal though: 2.8 million dead in 140 days. However, 1.8 million people never get the disease, which is a good demonstration that quarantine would be effective and it is comparable but not quite as effective as quarantine was with SARS. There are fewer people in the recovered class; this is because fewer people get infected.

Shifted virus with anti-viral treatment: q = 0, nu = 0.1 beta = 10^{-7}



Adding antiviral treatment to our model greatly affects the number of people in the recovered class: this is about 3.3 million within 80 days. The spread of the disease isn't slowed very much, as all but 0.3 million people have been infected within 50 days, compared to everyone being infected without treatment. Overall, we have 2 million more people recovered, and over 2 million fewer people dead with treatment as opposed to no treatment and no quarantine.

Shifted virus with anti-viral treatment and quarantine: q = 0.25, nu = 0.1 beta = 10^{-7}



When we combine both effects, we see that more than half of the population never becomes infected at all with this strain; only 2.5 million people get infected. After about 130 days this system stabilizes. Deaths are almost one million, but this is much better than over four million. We can see from the number of dead (0.9 million) versus the number of recovered (1.6 million) that less than forty percent of people who are infected die, and this is less than twenty percent of the population as a whole. This would still be catastrophic, but much less so than in a situation with no treatment or quarantine.

Conclusions

According to our model:

If there was a shift in the virus, and an outbreak in a city the size of Toronto, the entire population would be infected and 75% would die within 100 days.

Quarantine may not be as effective as it was with SARS (only 9.6% death rate for SARS), but it would save over one million lives.

With antiviral treatment, almost 2 million more recover from the disease. If we consider treatment to be 80% effective, then we estimate that 2.4 million people would need to be treated with these drugs, in order to control the outbreak.

These numbers are similar to those seen with the Spanish Flu outbreak after the First World War: both are the results of a dramatic shift in the influenza virus.

References

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