Research exercise: Infectious Disease Mathematical Modeling of the 2001 Foot and Mouth Outbreak

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Applying Mathematical Epidemic Modeling to Discover Commercially Beneficial Outbreak Control Methods
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Abstract
This is a mathematical analysis and computational study of the 2001 foot and mouth disease epidemic in the UK. This model includes an analysis of the basic SIR model, with three additional features: vaccination, culling, and an incubation or latency period. The introduction period refers to the initial population which represents the proportion of the entire population which initially contracted the disease but does not show symptoms. It is the proportion of the population which will be vacinees. It is the proportion of the infected population which will be removed from the infected population due to culling. Without any control policies the spread of foot-and-mouth disease will have a catastrophic toll on the livestock population. As shown in figure 7 below, the rate at which culling and vaccination must occur for there to be more healthy livestock than infected livestock; and figures 6 and 7 show the rate at which culling and vaccination must occur for there to be more healthy livestock than infected livestock. The SLIR model (or SEIR) is derived from the basic SIR epidemic model with an additional compartment, L which represents the latent or exposed population. The susceptible population (S) represents the population of livestock that may be infected with the disease; the infective population (I) represents the livestock population that is infected with the disease; and the removed population (R) represents the livestock population that either died or recovered from the disease. The model is used to determine the best control techniques for controlling the spread of foot and mouth disease during an outbreak.

Back Ground
Foot-and-mouth disease (FMD) is a highly contagious disease that affects cloven-hoofed animals; such as pigs, cattle and sheep. It can have disastrous effects on a country’s food supply and economic value. The infected animals are often slaughtered and disposed of far from the herd. Culling and vaccination can be employed in conjunction to successfully battle the spread of the disease during an outbreak. Mathematical epidemic modeling can provide government officials with useful information on how to effectively control the spread of the disease during an outbreak.

SLIR Model
The SLIR model (or SEIR) is derived from the basic SIR epidemic model with an additional compartment, L which represents the exposed population. The susceptible population (S) represents the livestock population that may be infected with the disease; the infective population (I) represents the livestock population that is infected with the disease; and the removed population (R) represents the livestock population that either died or recovered from the disease. This model is used to determine the best control techniques for controlling the spread of foot and mouth disease during an outbreak.

Components of SLIR Model
- \( a \) = rate of culling infectives
- \( b \) = rate of culling susceptible
- \( c \) = rate of culling infectives
- \( d \) = incubation/latency period
- \( e \) = rate of culling latents

Assumptions of Model
- There is a rate of vaccination of susceptibles proportional to both the number of susceptibles and the number of vaccinates.
- The vaccinates are assumed to be removed from the susceptible population immediately.
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Back Ground
Foot-and-mouth disease (FMD) is a highly infectious disease caused by an aphthovirus that affects cloven-hoofed animals such as pigs, cattle and sheep. It is the goal of this analysis to more accurately determine the rate at which vaccination and culling should be applied and which methods will result in greater commercial value for the livestock populations.

Model Sets Birth Rate Conditions So that the Ability to Locate Susceptibles
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Relevant Equations
\[
\begin{align*}
\frac{dS}{dt} &= aS - bS - dS - eS \\
\frac{dI}{dt} &= bS - cI - dI - eI \\
\frac{dL}{dt} &= cI - eL \\
\frac{dR}{dt} &= dL - eR
\end{align*}
\]

Flow Diagram

Results

Without any control policies the spread of foot-and-mouth disease will have a catastrophic toll on the livestock population. As shown in figure 7 below, the rate at which culling and vaccination must occur for there to be more healthy livestock than infected livestock; and figures 6 and 7 show the rate at which culling and vaccination must occur for there to be more healthy livestock than infected livestock. The SLIR model (or SEIR) is derived from the basic SIR epidemic model with an additional compartment, L which represents the latent or exposed population. The susceptible population (S) represents the population of livestock that may be infected with the disease; the infective population (I) represents the livestock population that is infected with the disease; and the removed population (R) represents the livestock population that either died or recovered from the disease. This model is used to determine the best control techniques for controlling the spread of foot and mouth disease during an outbreak.

References and Acknowledgments
[8] Special thanks to Trevor Wood for providing a general model technique in his paper: Mathematical Epidemic Modeling.

Conclusion
When no control policies are employed the economical results are obvious. A mixture of vaccination and culling with significantly positive results towards the containment of the disease. While culling is a much more effective method of control, vaccination can be a valuable precautionary policy. Any animal that remains disease free or does not contract the disease is still contributing greatly to the control of the disease, can still contribute positively towards the economical value of the livestock population. The problem is vaccination can save over 90% in cost but it also requires more livestock. While the manufacturing cost of the vaccine is fairly cheap, about 60 cents, I cannot speak to what a country’s government may provide per animal and price the vaccine for. Additionally, the cost of obtaining people to apply the vaccine can be a large investment. Additionally, there is also a high level of vaccination results in an appearance of 1% increase of vaccinates available for commercial use. While vaccinates cannot be vaccinated they can still be used locally and disposed of at the local farm or other local farm.

Benefits of Culling
Vaccination is a great benefit to the affected country but is not contributing greatly to the control of the disease. It is important to remember that this is a simple quadratic model and in reality there are many factors, such as spatial factors, that could change these results. It is not uncommon for large animal farms, such as swine and dairy cows, will create large enough commercial profits to justify the additional cost to be vaccinated at a high rate.

Population Available for Commercial Use

High rate of vaccination increases the amount of livestock available for commercial use by approximately 10%.

Population Available for Commercial Use

Figures 6 and 7 show the rate at which culling and vaccination must occur for there to be more healthy livestock than infected livestock. The SLIR model (or SEIR) is derived from the basic SIR epidemic model with an additional compartment, L which represents the latent or exposed population. The susceptible population (S) represents the population of livestock that may be infected with the disease; the infective population (I) represents the livestock population that is infected with the disease; and the removed population (R) represents the livestock population that either died or recovered from the disease. This model is used to determine the best control techniques for controlling the spread of foot and mouth disease during an outbreak.

Mathematical Epidemic Modeling: Applied to Foot and Mouth Outbreak

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