Animal Disease Spread Modeling for Epidemiological and Economics Purposes: Learning from the 2015 Highly Pathogenic Avian Influenza Outbreak

Melissa Schoenbaum, Kelly Patyk, Amy Delgado, Columb Rigney
USDA–APHIS–VS–STAS–CEAH
Fort Collins, Colorado
Melissa.Schoenbaum@aphis.usda.gov, Kelly.A.Patyk@aphis.usda.gov,
Amy.H.Delgado@aphis.usda.gov, Columb.P.Rigney@aphis.usda.gov

ABSTRACT

Simulation modeling is a well-established and essential tool for epidemiologic investigations, including population disease dynamics and the evaluation of mechanisms for disease control. Agricultural economic models allow users to go beyond disease impacts to explore the cost implications of animal disease. The United States Department of Agriculture's Center for Epidemiology and Animal Health uses a variety of modeling tools to answer critical questions for planning and policy. In addition to describing some of these modeling tools, this presentation also covers some lessons learned while supporting the 2015 avian influenza outbreak.

ABOUT THE AUTHORS

Melissa Schoenbaum is a biological scientist with the USDA–CEAH–Monitoring and Modeling unit. She received her BS in biological sciences from East Texas State University and her MS in computer information technology, with a database emphasis, from Regis University. She serves as the modeling team's data management specialist and is the technical liaison with developers during software development projects.

Kelly Patyk is a veterinary medical officer for the USDA–CEAH–Monitoring and Modeling unit. Kelly received her Master of Public Health degree from the University of Colorado, Denver, and her Doctor of Veterinary Medicine from Colorado State University. As a member of the Monitoring and Modeling unit, she serves as an epidemiologist engaged in the application of simulation models of highly contagious diseases of livestock and poultry for emergency preparedness.

Amy Delgado currently serves as a veterinary epidemiologist with the Monitoring and Modeling Unit of the USDA–CEAH in Fort Collins, CO. Her work focuses on providing scientific support for emergency response planning for trans-boundary animal diseases. Dr. Delgado received a Bachelor´s and Master´s degree in animal science prior to receiving her Doctor of Veterinary Medicine and PhD in epidemiology from Texas A&M University.

Columb Rigney is a veterinary epidemiologist at the USDA–CEAH–Monitoring and Modeling unit in Fort Collins, CO. His work primarily focuses on configuring models to develop animal-disease spread simulations. He received his Doctor of Veterinary Medicine degree from the University of Illinois. He also holds master's degrees in public health and public administration. He is a board certified in veterinary preventive medicine.

Animal Disease Spread Modeling for Epidemiological and Economics Purposes: Learning from the 2015 Highly Pathogenic Avian Influenza Outbreak

Melissa Schoenbaum, Kelly Patyk, Amy Delgado, Columb Rigney
USDA–APHIS–VS–STAS–CEAH
Fort Collins, Colorado
Melissa.Schoenbaum@aphis.usda.gov, Kelly.A.Patyk@aphis.usda.gov,
Amy.D.Delgado@aphis.usda.gov, Columb.P.Rigney@aphis.usda.gov

INTRODUCTION

The Monitoring and Modeling (M&M) Team is one of the groups within the Center for Epidemiology and Animal Health, part of the Science Technology and Analysis Services of the United States Department of Agriculture–Animal and Plant Health Inspection Service–Veterinary Services. In the agriculture world, this team is well known for housing the National Animal Health Monitoring System (NAHMS). NAHMS conducts national studies of U.S. livestock and poultry to derive timely and factual information about animal health and management practices, with a vision of providing comprehensive US animal health information to the world. This team is a multidisciplinary group of veterinarians, epidemiologists, agricultural economists, statisticians, biologists, and specialists in GIS, commodities, and wildlife ecology. Support is provided by technical editors and information technology staff.

Animal health is a broad topic, covering disease prevention and control, animal welfare, production and management practices, food product wholesomeness, environmental considerations, and economic issues such as trade in animals and animal products. To realize our vision, we work with representatives from multiple local, state, and federal government agencies; academic institutions; industry organizations; and individual producers. By combining our skills, knowledge, and resources with our collaborators, we achieve much more than we could alone. The Modeling Team aims to lead the evaluation, acquisition, and enhancement of applied animal-disease models based on supportable epidemiologic and economic principles, effectively communicate modeling results through training and outreach, and support federal and state emergency management in animal disease outbreak response and preparedness. Specifically, the models address animal diseases that are highly contagious and may cause disruption to the food supply.

MODELING ANIMAL DISEASE SPREAD

There are several groups that use the information our models provide. As an example, model outputs provide emergency management teams from federal, state and local governments with realistic scenarios to conduct training exercises. Model outputs may also inform policy and practices during an outbreak response. When looking at a question for analysis, a wide range of scenarios are examined, with multiple iterations of each scenario run in order to evaluate a broad range of possible outcomes.

Modeling disease transmission and control in livestock and poultry populations has some differences as compared to disease modeling in human populations. Although livestock and poultry move between physical locations when taken to market or to harvest, there is not the same freedom of movement as observed in human populations. To address this, livestock and poultry are modeled as stationary units that represent a group of animals (i.e., a herd or flock) with specific within-herd/flock dynamics. Herd/flock to herd/flock movements and disease spread are often modeled separately. Another key concept in simulating animal disease spread is understanding that multiple species may be involved in a disease outbreak, and groups of animals may be managed or moved differently based on their intended purpose. Differences in intra- and interspecies management practices can contribute to variability in disease spread and the effectiveness of control options. In order to account for these differences, we use "Production Types" to define both a species and purpose for groups of animals. Examples of cattle production types included in our models are: dairy herds, cow calf operations, feedlots, and stockers. The age of the animals present and their management would vary greatly among each of these different farm types.

CONCEPTS FOR ANIMAL DISEASE MODELS

There are three main components required in an animal disease model. First, the population of livestock or poultry that is susceptible to a given disease must be identified. This population is provided as a data file that includes the production type of the animals, the size of the herd/flock, and their geographic coordinates for the model. The second component is the set of parameters that define disease manifestation and transmission. These often vary by species or age of the animal. Finally, the model includes measures that can be taken to control the disease. Control measure parameters may include movement restrictions, tracing of direct and indirect contacts which triggers additional detection of infected herds/flocks, zone-based surveillance, depopulation of infected herds/flocks, and vaccination of herds/flocks at risk.

MODELING SOFTWARE APPLICATIONS

M&M uses several software applications to accomplish our objectives. InterSpread Plus ® (ISP) and the North American Animal Disease Spread Model/Animal Disease Spread Model (NAADSM/ADSM) are the most commonly used applications to simulate animal disease spread and control. Both applications are stochastic state-transition models and provide a flexible SLIR (susceptible/latent/infected/removed) framework for users to simulate disease progression and spread by contact or air. Outbreak control measures such as vaccination and depopulation can be implemented, while accounting for resource limitations in personnel or supplies.

The economic impacts of an animal disease outbreak are broad, including both direct and indirect costs. Direct costs associated with the control of the outbreak include human resources needed for an emergency response, indemnity for animals which are depopulated to control disease spread, and the costs of eliminating the pathogen from the farm. There are also indirect costs, such as trade restrictions and changes in consumer demand, which may have far-reaching consequences on the United States economy.

Economic analysis is facilitated by the Paarlberg model, which is a quarterly, national partial-equilibrium model of the livestock and feed-grain sectors of the United States. The model uses a set of baseline conditions on supply, demand, trade, and user-defined shocks to estimate the economic impacts of an outbreak on livestock and grain markets, consumers, and producers.

HOW ARE THESE MODELS USED?

M&M uses models to answer questions related to the epidemiological and/or economic consequences of an animal disease outbreak. Frequently, these models are used in an integrated analysis to assess animal health and economic impacts. The types of questions that our team may address include:

- What does a worst case outbreak look like in terms of the number of animals infected?
- How long might an outbreak last?
- What are the anticipated effects on consumers, particularly related to the food supply?
- Is there an advantage to early detection of disease? Can this advantage be described in epidemiologic and economic terms?
- How effective is a targeted control strategy, such as vaccination or depopulation? What is the most cost-effective solution?
- What sort of surge in diagnostic laboratory capacity can be expected in support of an outbreak?
- What demand for resources (human and other) may be created by the outbreak?

HIGHLY PATHOGENIC AVIAN INFLUENZA, 2015 – LESSONS LEARNED

During the 2015 outbreak of highly pathogenic avian influenza (HPAI) in the United States, M&M provided information to support emergency response and planning. Since the disease was first identified in the United States in December 2014 in the Pacific Northwest, HPAI has been detected in commercial and backyard poultry flocks, wild birds, or captive wild birds in 21 states. During the outbreak, which ended in June 2015, 211 commercial and 21 backyard poultry premises were affected. The outbreak resulted in the depopulation of 7.5 million turkeys and 42.1

million egg-layer and pullet chickens, with devastating effects on these businesses, and a cost to federal taxpayers of over $950 million (USDA, 2015).

A series of scenarios was modeled to derive possible outbreak outcomes based on comparative start locations, variability in the infectivity of the pathogen, and alternative control activities. In the absence of an outbreak, the Modeling Team often communicates study results using peer-reviewed publications or conference presentations/posters. During the outbreak, results were needed quickly in order to be useful for decision-making. There were several lessons learned as our team made the switch to a rapid-response mode.

Modeling Concepts are often not familiar to Management

Models were "wrong" because they did not perfectly replicate the outbreak. Helping decision-makers interpret stochastic modeling results was an important communication goal.

Communication of Complex Topics

Communication of complex topics requires thoughtful presentation. Presentation methods commonly used in scientific publications often lead to confusion. There was a learning curve required for both modelers and policy-makers in learning how to discuss modeling results and their relevance to the emergency response process. Rapid and effective visualization of modeling results require creativity.

Data Gaps

During the initial stage of an outbreak, there are often significant gaps in what is known about the behavior of the disease. As a result, the parameterization of the models is often a work in progress, requiring close communication with partners in the laboratory and the field.

Resource Demands

The dynamics of an outbreak response will result in a high demand for resources, both for analysts to develop parameters and analyze scenarios as well as for computing resources to run simulations. These resource requirements may last for many months, with questions from policy-makers increasing as the outbreak response wanes. As a result, the demands on the modeling team resources increased, even when the rest of our organization was standing down.

Model Parameters Changing in Real Time

The use of models to inform the outbreak response meant that the parameterization of the models needed to be transparent and responsive to feedback. Since the outbreak involved a novel virus for the U.S. poultry population, experimental or field studies to support parameters related to disease transmission or detection were not initially available, which required our team to actively analyze outbreak data to refine scenarios and improve parameters. Both the virus and the outbreak response evolved over time (e.g., onset of clinical signs in different species, time to attain laboratory diagnostic test results, time to depopulation), resulting in the development of modeling scenarios that incorporated these changes.

The data generated by the outbreak will provide an opportunity for further development and validation of our models. However, every outbreak is unique, and the parameters developed during this outbreak may not be relevant for future outbreaks. Parameterization is a never-ending challenge.

CONCLUSION

M&M involvement in this recent outbreak demonstrates the value that modeling and simulation provide to the USDA and to other state, federal, and industry stakeholders. The ability to explore control options or anticipate the impacts of changes in viral dynamics is an indispensable tool for emergency responders. However, the use of models during an outbreak brings additional challenges in terms of resource demands and handling uncertainty in model parameterization.

REFERENCES

Harvey, N., Reeves, A., Schoenbaum, M.A., Zagmutt-Vergara, F.J., Dubé, C., Hill, A.E., Corso, B.A., McNab, W.B., Cartwright, C.I., & Salman, M.D. (2007). The North American animal disease spread model: A simulation model to assist decision making in evaluating animal disease incursions. *Preventive Veterinary Medicine 82*, 176–197.

Paarlberg, P.L., Hillberg Seitzinger, A., & Lee, J.G. (2007). Economic impacts of regionalization of a highly pathogenic avian influenza outbreak in the United States. *Journal of Agricultural and Applied Economics 39*(2), 325-333.

Paarlberg, P.L., Hillberg Seitzinger, A., Lee, J.G., Matthews, K.H. (2008). *Economic Impacts of foreign animal disease* (ERR-57)**.** Washington, DC: U.S. Department of Agriculture, Economic Research Service.

Reeves, A., Hupalo, R., Patyk, K.A., and Hill, A.E. (2012). *User's guide for the North American animal disease spread model* (4^{th} ed.). Fort Collins, CO: Colorado State University. Retrieved from *http://www.naadsm.org*

Stevenson, M.A., Sanson, R.L., Stern, M.W., O'Leary, B.D., Sujau, M., Moles-Benfell, N., & Morris, R.S. (2013). InterSpread plus: a spatial and stochastic simulation model of disease in animal populations. *Preventive Veterinary Medicine, 109*(1-2), 10-24. doi: 10.1016/j.prevetmed. 2012.08.015

United States Department of Agriculture (USDA), Animal and Plant Health Inspection Service, Veterinary Services. (2015). *Fall 2015 HPAI preparedness and response plan.* Retrieved from https://www.aphis.usda.gov/animal_health/downloads/animal_diseases/ai/hpai-preparedness-and-response-plan-2015.pdf