Stochastic Model of the Potential Spread of Highly Pathogenic Avian Influenza (HPAI) from an Infected Commercial Broiler Operation in Georgia, U.S.

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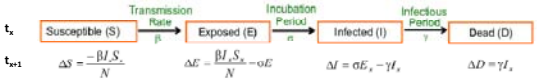
Summary

The potential spread of HPAI between commercial broiler farms in Georgia, U.S. was mathematically modeled. The dynamics of spread within the index flock was modeled using an SEIR deterministic model, and predicted that grower detection of flock infection is most likely 5 days after virus introduction. Off farm spread of virus was estimated stochastically for this period, predicting a range of exposed farms from 0-5 depending upon the density of farms in the area. Modeled off-farm spread was most frequently associated with feed trucks (highest frequency of visits and range of farms visited) and company personnel or hired help (highest level of contact).

ON-FARM Spread Model – DETECTION DAY under diverse virus virulence characteristics

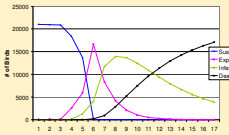
A compartmental epidemic (SEIR) model was used to estimate the days to grower detection of flock infection following the introduction of a highly pathogenic avian influenza (HPAI) virus.



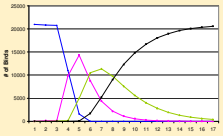
Dynamics of the SEIR model in a poultry house with a 21,000 bird capacity and introduction of a single infected bird on day zero:

•Incubation period (σ) = 2 days
•Daily transmission rate (β) = 70 birds/infected bird

Infectious period = 6 days



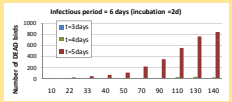
Infectious period = 3 days

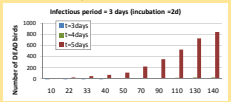


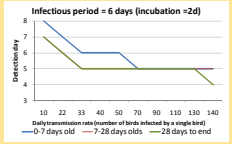
Using these parameters, time to detection was estimated for different scenarios of virus virulence, as shown in the panel to the right.

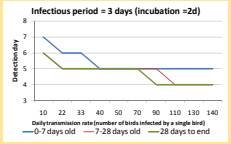
Mortality thresholds have been shown by other studies to be the most reliable indicator of AI infection in many poultry production systems (1, 2). Our model used the average mortality threshold reported by Vieira *et al* (3) of 0.2% (reported range 0.04 to 1.08%) to determine the most likely day of grower detection of flock infection on the index farm. According to our model the most likely day of illness detection is the 5th day across the range of reported average mortality levels tolerated by commercial poultry growers.

The estimated detection day of t=5 was fairly robust across varying parameters of:
Virus incubation period (range: 1 to 4 days)
Infectious period (range: 1 to 10 days) and
Transmission rates (22 to 140 birds per infected contact)









OFF-Farm Spread Model – translating contact information and farm density into predictions of HPAI spread among farms

Visitor comes to Index farm Bernoulli (p) **X** **Visitor is contaminated** Bernoulli (p); **p = probability of contamination** Uniform (min,max) → **f(y)** → **If f(y) > 0, the visitor spreads** → **Number of farms exposed (Each visitor was assigned one of the following distributions):** Uniform (min,max) Poisson (λ) β-Pert (min,most lik.,max)

The stochastic off-farm model predicted the contact rate between farms, based upon the movement of people, vehicles, and equipment from the index farm to other farms in the same day. The identification of human activities and their frequency were obtained from a poultry grower survey. (3) Spread from the index farm was assumed to be possible after two days of infection, after the initially infected birds on the reached the end of their incubation period and became infectious.

Spread is assumed to occur if:

(1) A visitor comes to the index farm. This event is simulated by a Bernoulli trial which probability of success is represented by the daily chance of that specific visitor coming to the farm (flock frequency/49; as an average growout period would be of 49 days).

(2) The visitor contacts infected birds, or potentially infective material, and becomes contaminated. In the table, period refers to whether the activity is performed during the interval between flocks (I), while flocks are in the houses (F), or possible at anytime (A). The probability of a visitor getting contaminated ("Cont."), for each activity, was classified as "none", "very low", ""low", "moderate", "high" and "very high". Each of the five non-zero risk categories is represented in the model by a uniform continuous distribution, with mutually exclusive ranges of equal size (0.20) from zero to one. Once a probability is drawn in one trial, it's used in a Bernoulli trial (yes-no event).

Prevalence is the proportion of specific scenarios considered for each activity, or the proportional weight of each listed item within the same visitor type

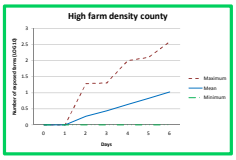
(3) The visitor (now a vector) goes to other farms. The outcomes of the first two events are multiplied, and if the result is not zero (both of them occur), the number of contacted farms will be determined by the range of visits for the vector. A uniform (discrete) distribution represented the range in the number of farms that could be visited in a day after a visit to the index farm.

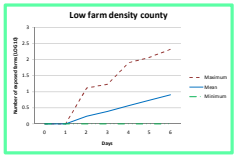
Table notes:
**Frequency of total house clean out, times the reported frequency of growers disposing litter off-farm
***No growers reported disposal of dead birds off-farm

	Activity	Period	Cont.	HIGH DENSITY COUNTY Flock Freq.	Prev.*	Max farm range/day	LOW DENSITY COUNTY Flock Freq.	Prev.*	Max farm range/day
1	**Clean Out Services**	I		0.33			0.33		
	Owned Equipment		0		0.50	0		0.90	0
	Borrowed Equipment		Low		0.10	2		0.00	2
	Contracted Services		Mod.		0.40	2		0.10	2
2	**Decaking, Housekeeping**	I		0.25			0.25		
	Owned Equipment		0		0.90	0		0.95	0
	Borrowed Equipment/Contracted		Low		0.10	2		0.05	2
3	**Disposal of Litter off-farm**	I	VH	0.25**	1.00	1	0.25**	1.00	2
4	**Disposal of Birds off-farm**	F	VH	0***	1.00		0***	1.00	
5	**Live Haul**	F	VH	1	1.00	3	1	1.00	1
6	**Shaving Suppliers**	I	Mod.	0.33	1.00	2	0.33	1.00	2
7	**Repairmen**	A		0.25		3	0.25		3
	Growout / Inside		High		0.75			0.80	
	Growout / Outside		Mod.		0.15			0.10	
	Downtime		Low		0.10			0.10	
8	**LP Delivery**	A				5			3
	Winter / Downtime		Low	3.00	0.17		3.00	0.17	
	Winter / Growout		Mod.		0.34			0.34	
	Summer / Downtime		Low	0.33	0.16		0.55	0.16	
	Summer / Growout		Mod.		0.33			0.33	
9	**Feed Trucks**	F	Mod.	15.00	1.00	5	15.00	1.00	5
10	**Chick Bus**	I	Mod.	1.00	1.00	5	1.00	1.00	5
11	**Service Persons, Managers, Vets**	F	VH	7.00	1.00	5	7.00	1.00	4
12	**Utilities, Meter readers, Pit inspect.**	A		1.00		15	1.00		10
	Downtime		Low		0.25			0.25	
	Growout		Mod.		0.75			0.75	
13	**Unauthorized Visitors**	A		4.00		2	2.00		2
	Inside		VH		0.25			0.50	
	Outside		Low		0.75			0.50	
14	**Vaccination Crews**	F		0.50		5	0.50		5
	Vaccine		High		0.50			0.50	
	No Vaccine		0		0.50			0.50	
15	**Grower, Hired Help**	F	Mod.	14.00	1.00	2	14.00	1.00	2

Results

Number of farms potentially exposed to contamination from an infected index farm via human movement in a 24hr interval in a high poultry farm density region (1.45 farms/5 mi²) and a low poultry farm density region (0.49 farms/5 mi²)

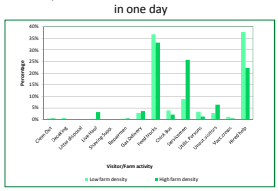




Probability that HPAI infection is not transmitted from the index farm in the days following initial flock infection (Day 0). Calculations assume that off-farm spread of virus from the index farm is not possible until Day 2.

Probability of a HPAI infection being restricted to the index farm							
Farm density	**Day 0**	**Day 1**	**Day 2***	**Day 3**	**Day 4**	**Day 5**	**Day 6**
Low	100%	100%	69.5%	47.6%	33.3%	22.3%	15.3%
High	100%	100%	67.4%	47.5%	33.3%	23.1%	16.3%

Proportional contribution of each listed visitor to the overall spread of HPAI virus from one infected farm in one day



Conclusions and discussion

Under several potential scenarios, an introduction of HPAI in commercial poultry farms would be detected in the 5th day of spread.

Immediate reporting following detection is critical to prevent expansion of outbreak, since the number of exposed farms increases exponentially by the time of detection on the index farm.

Most off-farm exposures were associated with feed trucks and human contacts associated with in-house contact with birds, such as company service personnel and hired help. Use of non-family hired help was reportedly more common in the low farm density area, while the growers in the highly poultry dense area were more likely to report visits from non-company personnel (unauthorized visitors), which is reflected in the results.

The actual number of infected farms resulting from exposure to a single index farm would be lower than the estimates shown here. The reduction of transmission risk associated with on-farm biosecurity and virus decay during transport were not included in this model. Nonetheless, by using data on detection thresholds and horizontal contact rates reported by broiler poultry growers in Georgia, we were able to model the likely pathways for virus spread under realistic conditions.

The observed results highlight the need for early reporting of flock illness and the importance of biosecurity focused on key high risk activities.

NEXT STEPS : Role of biosecurity measures – modeling the effectiveness in reducing HPAI spread

This work showed the potential risk of farm exposure to a highly virulent virus associated with human movement between an infected commercial poultry farm and other susceptible farms. This made clear that further developments of the model are needed to examine the role of farm biosecurity in preventing virus spread. To expand the model, two extra sources of information will be used:
(1)Field experiments demonstrating the efficiency of specific biosecurity measures;
(2)Information regarding the biosecurity measures as applied by broiler growers in Georgia. This information was obtained via a survey of growers.

Model expansion:

Results of the survey of growers: Which biosecurity measures are routinely adopted to reduce the chance of a visitor leaving the farm contaminated.

Field experiments How effective each of the practiced biosecurity measures is on preventing contamination of the visitor

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References:
(1) Elbers, A. R., Holtslag, J. B., Bouma, A., and Koch, G. Within-flock mortality during the high-pathogenicity avian influenza (H7N7) epidemic in The Netherlands in 2003: implications for an early detection system. Avian Dis. 51:304-308. 2007.
(2)Savill, N. J., St Rose, S. G., and Woolhouse, M. E. Detection of mortality clusters associated with highly pathogenic avian influenza in poultry: a theoretical analysis. J. R. Soc. Interface . 2008
(3)Vieira, A. R., Hofacre, C. L., Smith, J. A., and Cole, D. Human contacts and potential pathways of disease introduction on Georgia poultry farms. Avian Diseases . In press

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